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Journal

of

THE ROYAL AERONAUTICAL SOCIETY

JUNE 1953

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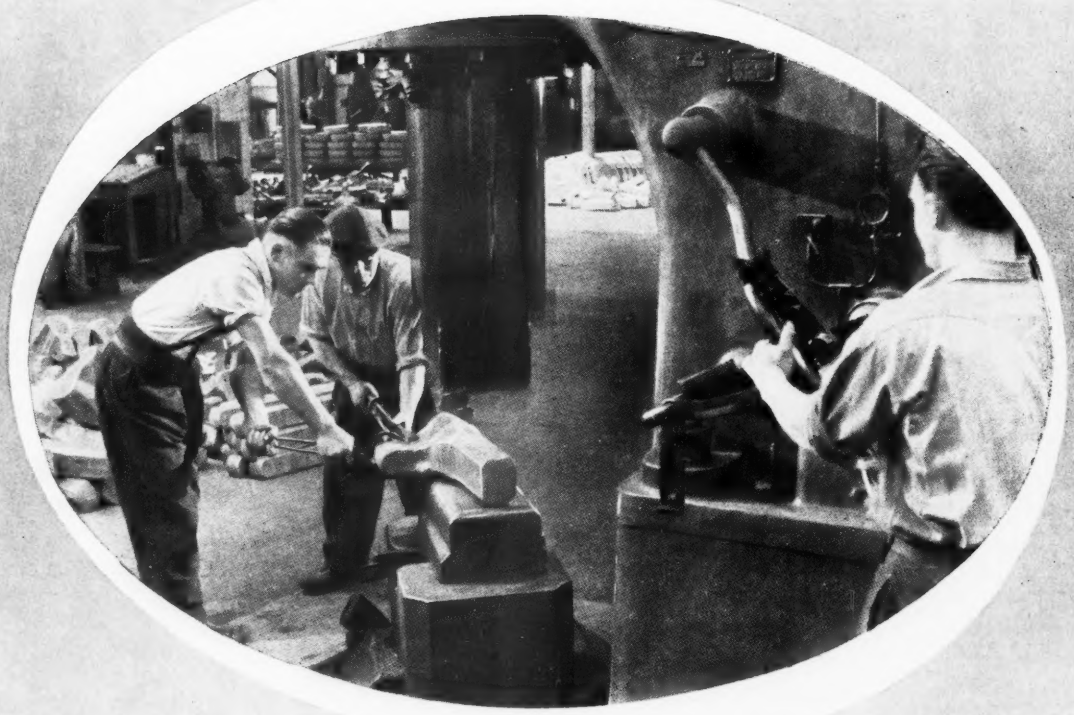

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Journal of

THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

PUBLISHED MONTHLY AT

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All communications for publication in, and advertisements for, the Journal should be addressed to the Editor, Joan Bradbrooke, A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary, A. M. Ballantyne, T.D., B.Sc., Ph.D., A.F.R.Ae.S.

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless stated otherwise.

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The Royal Aeronautical Society

(Founded 1866)

PATRON
HER MAJESTY THE QUEEN

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NOTE. The Vice-Presidents are elected at the May Meeting of Council.

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Solicitor: L. A. WINGFIELD, M.C., D.F.C. (*Associate*)
Secretary: A. M. BALLANTYNE, T.D., Ph.D., B.Sc. (*Associate Fellow*)

NOTICES

JUNE, 1953

Election of New President

Sir William S. Farren, C.B., M.B.E., M.A., F.R.S., F.R.Ae.S., has been elected President of the Society for the year 1953/54 and took office at the Annual General Meeting on the 7th May 1953.

Council for 1953-54

The following are the newly-elected Members of Council:

Professor A. D. Baxter, M.Eng., M.I.Mech.E. (*Fellow*).

A. G. Elliott, C.B.E., F.R.S.A., M.S.A.E., M.I.Mech.E. (*Fellow*).

Sir Harry M. Garner, K.B.E., C.B., M.A. (*Fellow*).

The following were re-elected to the Council:

Sir John S. Buchanan, C.B.E., A.M.I.Mech.E. (*Fellow*).

A. A. Hall, M.A., F.R.S. (*Fellow*).

E. T. Jones, O.B.E., M.Eng. (*Fellow*).

P. G. Masefield, M.A., F.I.A.S. (*Fellow*).

Annual General Meeting

The Annual General Meeting of the Society was held at 4 Hamilton Place, W.1, on 7th May 1953, at which the Annual Report and Balance Sheets of The Royal Aeronautical Society and Aeronautical Trusts Ltd. for 1952 were approved. The complete Report and Balance Sheets were published in the April 1953 Journal.

The following elections to Fellowship were announced at the Annual General Meeting:

L. Boddington
M. J. Brennan
E. E. Chatterton
J. M. Gray
C. N. Jaques
A. A. Lombard
B. K. O. Lundberg
W. R. McGaw
H. Pearson
H. Povey
B. E. Stephenson
H. Templeton
H. J. van der Maas

British Commonwealth and Empire Lecture

Members are reminded that the Ninth British Commonwealth and Empire Lecture will be given on Thursday 11th June 1953 at 6 p.m. at the Royal Institution, 21 Albemarle Street, W.1, by Sir Hubert Walker, C.B.E. The title of the Lecture is "Some Problems in the Development of Air Transport in West Africa." Tea will be served at 5.30 p.m.

Society of British Aircraft Constructors' Educational Grants

The attention of members is drawn to the Society of British Aircraft Constructors' Educational Grants administered by the Society.

The Grants are designed for the assistance of young men who are unable, for financial reasons, to obtain training in aeronautical engineering. All holders of S.B.A.C. Grants are expected to qualify for a technical grade in the Royal Aeronautical Society.

Applicants should be between the ages of 16 and 18 on 1st September in the year of the award. The closing date for applications for this year is 30th June 1953. Application forms may be obtained from the Secretary.

Garden Party, 14th June 1953, Astwick Manor, Hatfield Aerodrome, Herts.

An application form for tickets for the 1953 Garden Party has been sent to all Members with registered addresses in the United Kingdom.

To mark the fiftieth anniversary of powered controlled flight an effort is being made to have a representative number of early and modern machines flying and in the static display. It is also hoped to have a number of interesting early engines on view. A souvenir programme will be printed to mark the event.

The Central Band of the Royal Air Force, conducted by Flight Lieutenant F. A. Gale, will play during the afternoon.

Tickets, which include tea and car park, are 10s. each for adults and 5s. 6d. each for children under fifteen years of age and are available to Members of the Society. Will those Members who have not yet applied for their tickets do so as soon as possible in order to help with the organisation.

Fourth Anglo-American Aeronautical Conference

A leaflet giving the list of papers to be read at the Fourth Anglo-American Aeronautical Conference, which is to be held in London from 15th-17th September 1953, was enclosed with the May Journal and Notices. With the leaflet was an application for enrolment which members are asked to complete when making their application—which must be returned by 31st July 1953.

Preliminary reports from the Institute of the Aeronautical Sciences indicate that an even larger contingent of delegates than in 1951 may be expected.

Members' New Appointments

T. E. Bowden (*Associate Fellow*) has left his position as Aeronautical Engineer with the Department of Civil Aviation at Sydney, Australia, and is now Senior Engineer with the Division of Aircraft Production at Sydney.

W. H. Hambrook (*Fellow*) has been appointed Technical Manager of Short Brothers & Harland Ltd. (reported as Technical Director in the April Journal in error).

G. S. Hislop (*Associate Fellow*) has been appointed Chief Designer of the Helicopter Division of the Fairey Aviation Co. Ltd. He was formerly responsible for helicopter development and the control of the Helicopter Experimental Unit of British European Airways.

C. I. McBeth (*Associate*) has recently been appointed Purchase Manager at Rolls-Royce Scottish Factories.

R. G. McCoy (*Associate Fellow*) has been appointed deputy service manager of the de Havilland Aircraft Company Ltd.

D. Rigg (*Associate*), formerly production superintendent with A. V. Roe and Co., Manchester, has now joined Vickers-Armstrongs Ltd., in charge of their aerodrome at Chilbolton.

Major C. J. Stewart (*Fellow*) has been appointed to the Board of Dowty Fuel Systems Ltd.

G. F. Watson (*Companion*) has recently been appointed Station Manager for British Overseas Airways Corporation at Gander, Newfoundland.

C. C. Young (*Associate Fellow*) has taken over the position of Chief Aeronautical Engineer with North West Industries Ltd., Edmonton, Alberta, Canada.

Diary

LONDON

June 11th

Ninth BRITISH COMMONWEALTH AND EMPIRE LECTURE. Some Problems in the Development of Air Transport in West Africa. Sir Hubert Walker, C.B.E.. At the Royal Institution, Albemarle Street. 6 p.m. Tea at 5.30 p.m.

BRANCHES

June 8th

Halton—Film Night. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.

June 15th

Halton—Rectified A.C. Generating Systems. G. W. Wakefield. Branch Hut, R.A.F. Station, Halton. 6.45 p.m

June 29th

Halton—Junior Members' Night. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.

GRADUATES' AND STUDENTS' SECTION

An all-day visit has been arranged to the U.S.A.F. Station at Withersfield, Essex, on Saturday 18th July 1953. Visitors will be able to inspect the Republic F-84 aircraft and associated equipment, together with the maintenance and operational control facilities. Lunch will be provided and there will be transport from Braintree Station connecting with the 10.40 a.m. train from Liverpool Street. If numbers permit, the reduced return fare will be 10s.

Numbers are strictly limited, and application must be made to the Honorary Visits Secretary of the Section, C. B. Redgate, *Graduate*, 83 Wandle Road, Morden, Surrey, **before 30th June.**

Money should not be sent with applications, but members are asked to state whether they intend to travel by train or private car.

It is hoped to arrange an all-day visit to the Royal Aircraft Establishment, Farnborough, in late August. Further details will be published later.

THE AERONAUTICAL QUARTERLY—VOL. IV, PART II

Part II, Volume IV of The Aeronautical Quarterly is now available from the offices of the Society at 7s. 9d. (including postage) per copy to members, or 10s. 3d. to non-members. The contents are—

On the Noise Emanating from a Two-Dimensional Jet Above the Critical Pressure	*Alan Powell*
Some Aspects of Laminar Boundary Layer Separation in Compressible Flow with no Heat Transfer to the Wall	*G. E. Gadd*
Buckling of Oblique Plates with Clamped Edges Under Uniform Compression	*W. H. Wittrick*
A Note on the Theory of the Constant-Area Mixing of Compressible Flows as Applied to High-Speed Wind Tunnel Design	*F. G. Irving*
A Note on the Performance of Ducted Fans	*Bryan Thwaites*
On the Resistance of Screens	*K. E. G. Wieghardt*
Flow Changes in Gases in which Mass and Impulse are Conserved	*L. G. Dawson*

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Donald Glyn Oliver (*from Graduate*)
Donald George Pearce (*from Graduate*)
Patrick James Sibley (*from Graduate*)
Edward Trim (*from Graduate*)

Associates

Peter Lester Crowcroft
Robert James Hayward
Hugh Trounce Pascoe

Graduates

Michael John Broad (*from Student*)
Geoffrey Michael Deacon (*from Student*)
Daphne Hazel Fairweather (*from Student*)
Thomas James Patrick (*from Student*)
Paul Simpkin (*from Student*)
Hugh John Todd Young

Students

William Brookes
David John Huggett
Michael Richard Henry Jeffries
Jack Gordon Baird McCall
Gerald Ivor Pauley
Albert Edward Rudd

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the following gifts to the library:—From Lord Brabazon, *Fellow*, a catalogue of the Aero and Motor Boat Exhibition 1909; from J. H. P. Brymer, Esq., various engine handbooks; and from F. A. Wilkinson, Esq., *Associate Fellow*, a copy of "Aeroplane Design and a Simple Explanation of Inherent Stability" by F. S. Barnwell and W. H. Sayers (1916).

JOURNAL BINDING

Self-Binder Cases

Self-Binder cases of the "Easibind" type are available from the offices of the Society. These binders are for members who do not have their Journals permanently bound, or who wish to keep their Journals together during the year for binding later.

These cases will hold 12 Journals which are kept in place by means of flexible steel wires. Journals can be inserted or withdrawn easily without damage, so preserving the contents for permanent binding later. The Journals will open flat at any page.

The binder is strongly made in durable dark blue leather cloth on stiff board covers and has gold lettering on the spine. The year is not blocked on the spine but there is a panel on which members who wish to use the binder as a permanent case can put the date.

The cost is 11s. 6d. each including postage and packing for either the size to fit 1952 and previous Journals, or for the size to fit the Journal from January 1953, which has been increased in size. Orders and remittances should be sent direct to the Secretary at the Offices of the Society and it is *important to state whether the old size or new size is required.*

Permanent Binding

There is no increase in the price of permanent binding of Journals. The prices are:—

1952 Volume (including packing and postage) 16s. 0d.
Previous Volumes (including packing and postage) 18s. 0d.

Journals, *with a note of the name and address of the sender*, should be sent direct to the Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

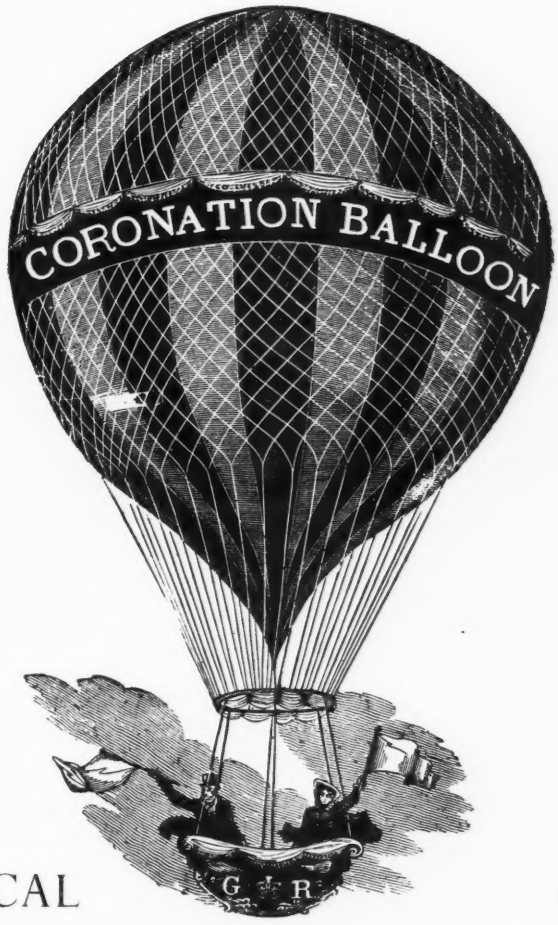
Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the JOURNAL for the following month.

Journal of The Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 57 JUNE 1953 NUMBER 510



HODGSON-CUTHBERT AERONAUTICAL COLLECTION

FROM A POSTER IN THE COLLECTION.

by

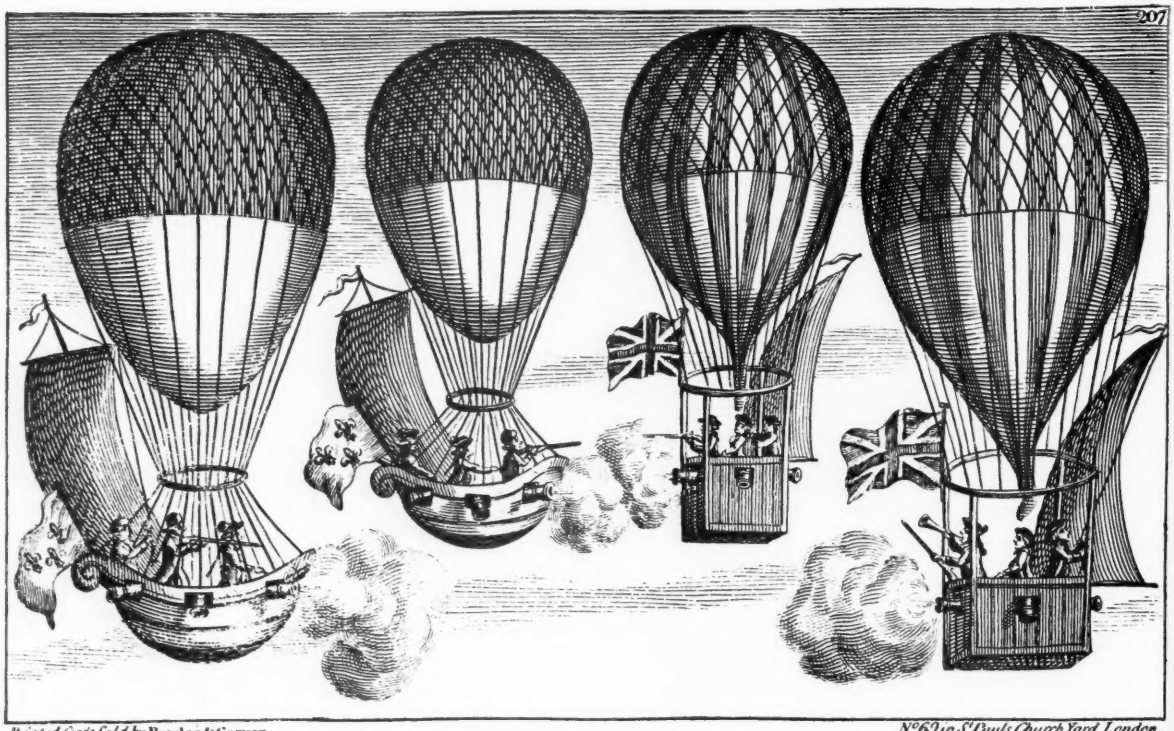
J. LAURENCE PRITCHARD, *Hon. Fellow*

(Captain Pritchard, who has been making notes for the long history of the Royal Aeronautical Society, here gives an account of one of its most remarkable possessions. He particularly wishes to acknowledge the help of "The Aeroplane" for the loan of colour blocks on pp. 354, 355, 359, 360, 361, 364 *and* 369.)

ON June 5th 1783, one hundred and seventy years ago, almost to the very day of the Coronation of Queen Elizabeth II, the first public "aerostatic experiments" were made which were to herald the dawn of a diuturnity of human endeavour.

In the Hodgson-Cuthbert Aeronautical Collection the Royal Aeronautical Society possesses a direct link spanning those one hundred and seventy years, a link which joins those wondrous days of long ago when people cried "What on Earth in Heaven is that?" with the present welfare days in which many have learnt how to move Heaven and Earth simultaneously atomically.

John Cuthbert, bitten by the collecting bug, left on record accounts of most of the early aeronauts and their


207
Printed for & Sold by Bowles & Carver.
N°69 in St Pauls Church Yard. London.
Behold an odd Fight, two odd Nations between,
Such odd Fighting as this was never yet feen; —
The BATTLE
of the
BALLOONS.
Published as the Act directs
But fuch Fights will be common (as Dunce to feel Rod)
In the Year of One Thouſand eight Hundred and odd.

voyages in the new element, but left no record of himself. It is known that he began his unique collection of contemporary aeronautical engravings and drawings and posters and other souvenirs, including fragments of famous balloons, sometime before the year 1820. It is also known that in 1837 he lived in Brook Street, Lambeth, and it is suspected that he was the John Cuthbert who was a Philosophical Instrument Maker of St. Martin's Lane, London, and who was awarded the Silver Medal of the Society of Arts in 1820 for a "Hydro-Pneumatic Apparatus."

That is all that is known of the founder of a remarkable aeronautical collection, one which has remained substantially more or less intact for over a hundred and thirty years. Cuthbert, like some others whose acquisitive desires outrun their moral upbringings, collected at times with a certain amount of ruthlessness, judging by the notes he made about some of his "finds."

These notes show that he was also acquainted with others of the time who were air-minded. He was a close friend of the unfortunate Robert Cocking, who lost his life in a parachute descent, in 1837, from a balloon. Cuthbert collected many contemporary drawings of the disaster and took an active part in raising a fund for Cocking's widow, in which he was assisted by another friend John Fillinham, who later acquired the Cuthbert collection. Fillinham was a collector on the large scale, and his collection of cuttings on antiquarian subjects now belongs to the British Museum. He added to Cuthbert's aeronautical acquisitions, later bought by George Edward Dering, an electrical engineer.

On the death of Dering the Cuthbert Collection came up for sale in the auction rooms of Hodgson and Co. and was bought by J. E. Hodgson, one of the partners in the firm. Hodgson became, in 1924, the Honorary Librarian of the Society. The worth of the collection he acquired may be gathered from Hodgson's own statement in his classic *The History of Aeronautics in Great Britain, from the earliest times to the latter half of the Nineteenth Century*. In an appendix to his *History* he wrote "The foregoing chapters, more particularly those dealing with ballooning, having been based to a large extent on the material contained in the Cuthbert Aeronautical Collection, it may be deemed useful to put on record some brief account of its inception and subsequent ownership." It is from that record that the foregoing still briefer note has been written.

Hodgson re-arranged the collection he had acquired, and annotated it. Many of the beautiful coloured and black and white plates were shown at the Royal Aeronautical Society's Exhibit at the International Aero Exhibition at Olympia in 1929, and subsequently in Berlin, and Hodgson received a number of offers for the collection. He had always hoped, however, that it would finally come to rest in the archives of the Society. That

the Society is now in possession is due to the generosity of both Sir Frederick Handley Page and John Hodgson himself, who allowed it to pass from his ownership in 1948, in which year it was bought and presented by Sir Frederick to the Society. Many of the remarkable engravings may now be seen on the walls of the Society's headquarters.

The time now seems opportune for giving some account of the oldest aeronautical collection in the world to the members of the oldest aeronautical Society in the world, many of whom are not fully aware of some of the unique aeronautical treasures possessed by the Society.

The information and the illustrations in this account are taken from the collection, but one can only select a few of the more significant and interesting items to describe, so that those members who cannot get to London may gain some idea of the years when gone with the wind meant more to a man in a balloon than it does now to a cinema proprietor.

The indefatigable Cuthbert collected everything from newspaper cuttings to cuttings from balloon envelopes. In the collection is a scrap of the fabric of the Hot Air balloon in which Pilâtre de Rozier made the first aerial flight ever made by a human being, at Paris on 21st November 1783. Cuthbert also obtained a fragment of the fabric of the balloon in which Pilâtre de Rozier lost his life in 1785 near Boulogne.

There are many other balloon fragments annotated by Cuthbert in his own handwriting. Only one more need be mentioned here, for it shows that Cuthbert stuck at nothing to add to his collection.

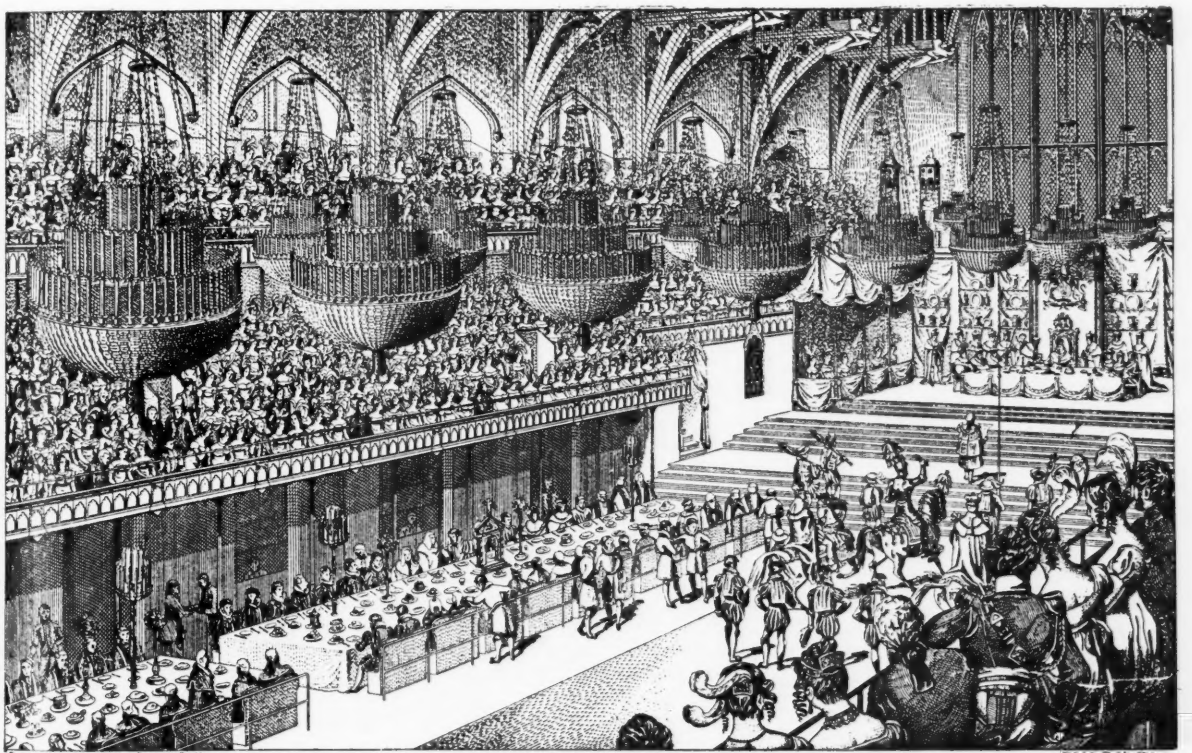
"A part of Blanchard's and Jefferies' balloon by which they crossed the Channel from Dover to Calais 1785. Procured from the Town Hall by myself, John Cuthbert."

I like the word *procured*!

Cuthbert also added a fragment of the fabric of the parachute which failed to function when Robert Cocking cut himself loose from the great Vauxhall balloon on 24th July 1837. Of more modern pieces of fabric there is one from Maxim's giant aeroplane of 1894.

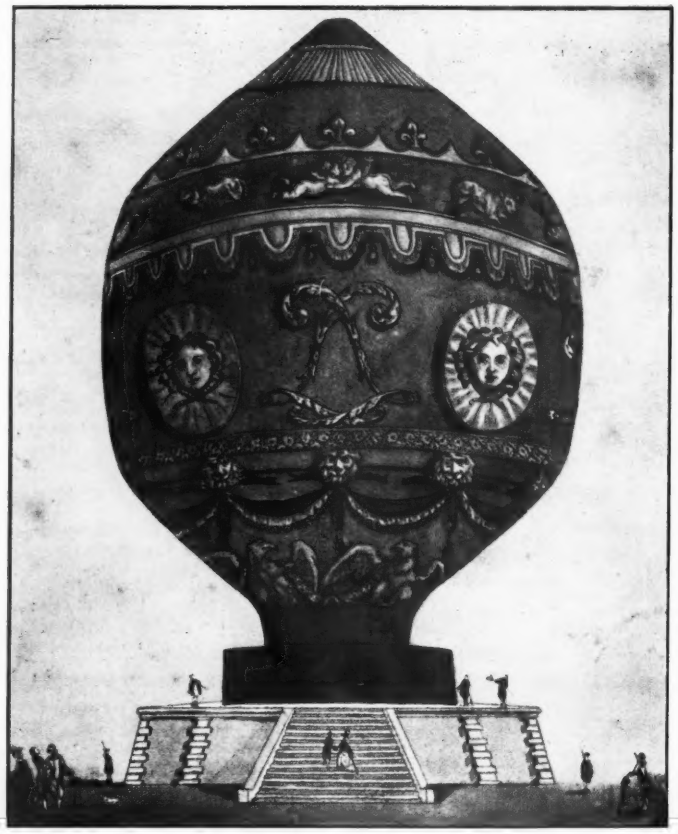
Among the many engravings and contemporary accounts of man's first aerial conquests are schemes for firework displays from balloons and for aerial warfare. These schemes had naturally, but dangerously, developed from firework displays given from kites for many years. John Bate published, in 1634, an account of how to make a kite for that purpose.

"You must take a piece of Linnen Cloth of a yard or more in length; it must be cut after the form of a pane of Glass; fasten two light sticks across the same, to make it stand at breadth; then smear it over with Linseed Oyl, and liquid Varnish tempered together, or else wet it with Oyl of Peter; and unto the longest corner fasten a Match prepared with Saltpeter water . . . . upon



A VIEW OF WESTMINSTER HALL DURING THE BANQUET GIVEN IN HONOR OF THE CORONATION OF HIS MOST GRACIOUS Majesty King George THE IV. 19. JULY. 1821

SHOWING THE CEREMONY OF THE KING'S CHAMPION THROWING DOWN THE GAGE.



THE MONTGOLFIER HOT-AIR BALLOON, 1783.

which you may fasten divers Crackers, or Saucissons; betwixt every of which binde a knot of paper-shavings, which will make it flie the better . . . . then tie a small Rope of length sufficient to raise it unto what heighth you shall desire, and to guide it withall; then fire the Match, and raise it against the wind in an open field, and as the Match burneth, it will fire the Crackers, and Saucissons, which will give divers blows in the Ayer."

What a lovely name it would have been for Flying Saucers, *saucissons*! Alas, they were only French sausages filled with gunpowder for firing a charge in military mining. In these days sausages give food for the mind but in those days for the mining. Fireworks from kites might have prolonged the life of the Ministry of Civil Aviation, but now it will have to be content with watching from the ground the Devil among the Transport Tailors.

No sooner had the first balloon risen in the air than caricaturists got busy. A few such caricatures are reproduced in this account. Cuthbert added many to his collection, from France as well as England, on every aspect of flying.

Beneath the contemporary caricature The Battle of the Balloons, first printed in 1784, and reprinted on a number of occasions in the early years of the nineteenth century, appeared the following lines (*see* p. 352):

" Behold an odd Fight, two odd Nations between.
Such odd Fighting as this was never yet seen;
But such Fights will be common (as Dunce to feel Rod)
In the year of One Thousand eight Hundred and odd."

Another engraving (not printed) shows The Grand Republican Balloon, 24th February, 1789, " intended to convey the Army of England from the Gallic Shore, for the purpose of exchanging French Liberty! for English Happiness! " and a poster of the date 2nd July 1848 from Brussels advertises the visit of the famous balloonist Henry Coxwell, one of the earliest Honorary Members of the Aeronautical Society, to show the " Balloon Incendiaire " for carrying " bombes, projectiles &c. destined to burn a town and put an army to flight." There is a coloured print of a Combat Aerien between two airships each armed with 100 guns!

The balloons seem to have had the advantage over modern fighters in that the opponents could fire when they saw the whites of each other's eyes. Now they chiefly see the black out of their own.

A hundred and fifty years ago, in 1803 to be precise, a projected attack on England by land, sea and air, was discussed by the French. The old French print reproduced here shows the sky swarming with balloons carrying armed men, the sea crowded with boats armed with mortars and guns blazing away, and the Channel tunnel packed with troops and artillery. The last boat pulling out from France carries the commanding officers on horseback, ready to gallop on to the landing beaches (*see* p. 357).

And how valiantly the British fought back according to the French artist! What mattered the direction of the wind? At Dover, as at Agincourt:

" Fair stood the wind for France
When we our sails advance,
Nor now to prove our chance
Longer will tarry."

So up went the man-carrying kites from the castle walls, and away in the opposite direction streamed the pennants of the British men-of-war. The balloons agreed with the pennants as to the direction of the wind and floated gallantly on with their grappling irons ready to claw those first early parachuteless jumpers out of the sky. It looks to me as though the French might have claimed to have had the first unified command of air, sea and land.

I began by saying that it was on 5th June 1783 that the first " aerostatic experiments " were made in public.

On that day, at Annonay, near Lyons, the brothers Montgolfier filled a large linen-backed paper balloon, 110 feet in diameter, with hot air and smoke from a wood fire. The balloon rose to a height of 6,000 feet and that first demonstration started something the end of which is not yet in sight.

On 15th October of that year Pilâtre de Rozier, greatly daring, made a captive ascent to a height of about 80 feet, and on 21st November 1783 he made the first free flight ever made by man, taking with him the Marquis d'Arlandes as a passenger. The two crossed Paris at a height of about 300 feet, and after a journey of a little over five miles in 25 minutes, landed safely.

The following December J. A. C. Charles, the well-known physicist and one of the brothers Robert, ascended in a hydrogen-filled balloon, the first of its kind, from the Tuileries Gardens, Paris. They remained in the air for two hours before descending at Nesle, after a journey of 27 miles. The illustration (*see* p. 359) shows the triumphant return of Charles and Robert to Paris on 2nd December 1783. When the balloon came down at Nesle it is recorded that Charles was met by an Englishman, J. J. Ferrier, and said "Moi, Charles, premier," an introduction perhaps even more significant in the history of the world than Stanley's famous, "Dr. Livingstone, I presume?"

The interest of the Royal Family in any new enterprise inevitably increases the interest of the public. In January 1784, just a month after Charles and Robert had made the first flight in a hydrogen-filled balloon, Professor Aimé Argand, a Swiss scientist, was summoned to Windsor Castle to demonstrate before King George III, the Queen and the Ladies of the Court, the new sensation (*see* p. 358). The King had already written in October 1783 to the President of the Royal Society offering to pay for the cost of experiments of air balloons, but the Council expressed the view that "no good whatever could result." Councils have a habit of expressing themselves that way. Maybe they are right.

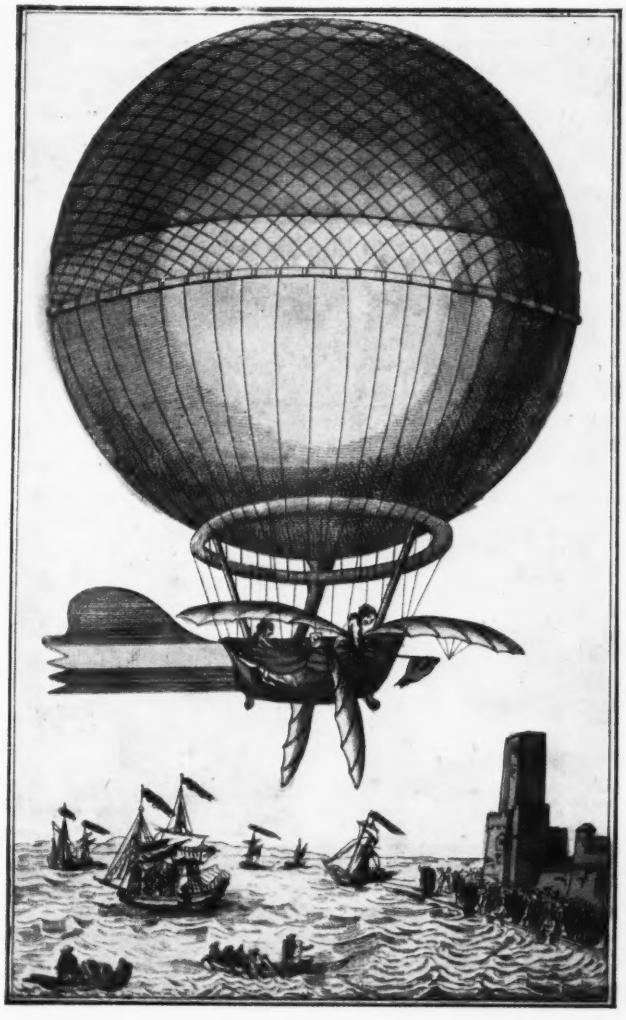
Many demonstrations were given in towns throughout England, and "Balloon Maker" became a profitable subsidiary sign attached to that of Umbrella Maker and others who made articles of oiled silk or similar material. The Air Age was faintly dawning and a new technology was to create a new industry, to give to mankind a new upward outlook. To some, the future held greater fears than hopes, for the Battle of the Balloons, in caricature, in serious Reviews, and in popular views, was something as inevitable as the clash between the nations since the world began.

Many, too, saw clearly that there were hopes of the long-awaited problem of the way of an eagle in the air being solved. Many are still hoping.

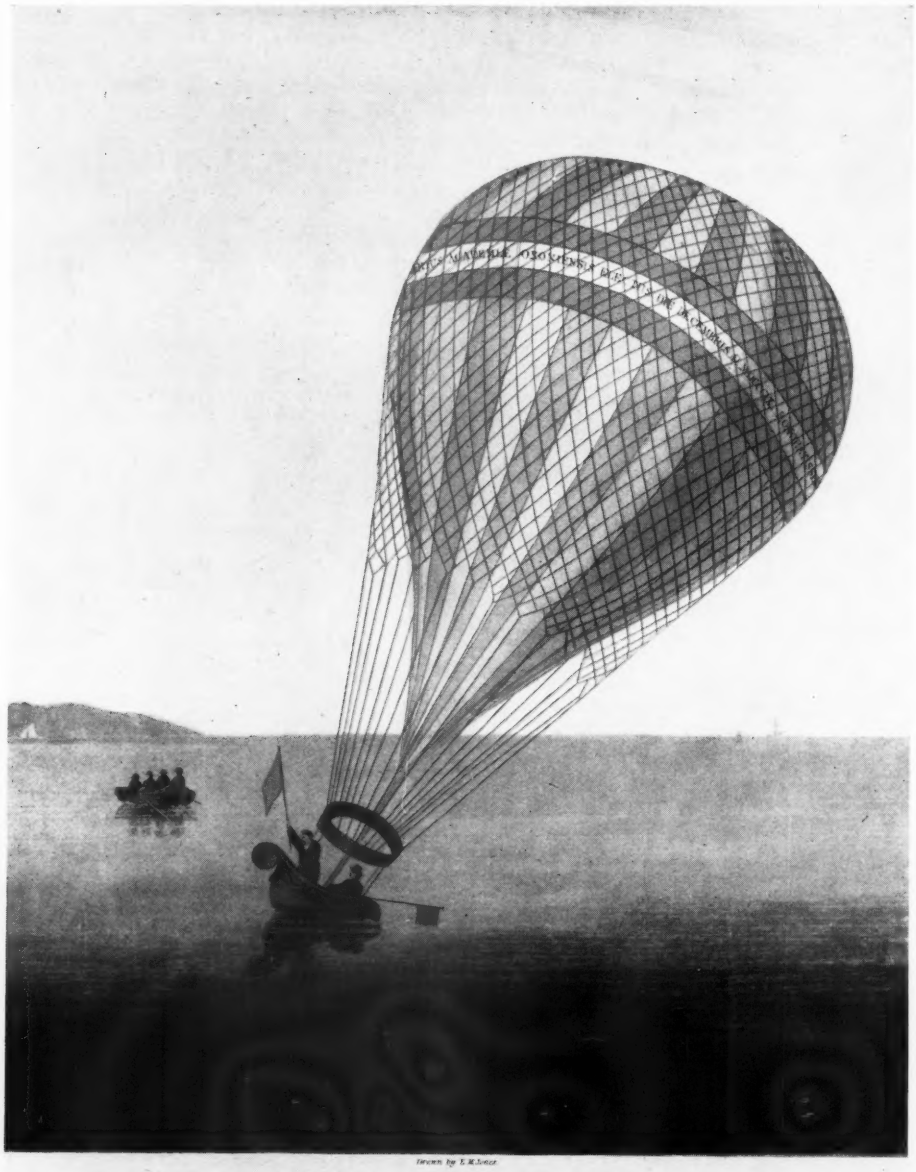
On 7th January 1785, Blanchard, the French aeronaut, made the first aerial crossing of the English Channel, with Dr. John Jefferies as passenger. Dr. Jefferies, an American citizen from Boston before tea was rationed, financed the considerable expenses of that flight. The Dr. Jefferies of the world have enabled the names of many otherwise forgotten pioneers to be added to the stirring annals of aeronautical achievement, side by side with their own. It is to be hoped that the examples so set and so frequent in the past will not become less so among the homogeneous humans of the future states of the world.

The story of that flight is as well known in New York as it is in Dover and Calais, and was told at some length by Dr. Jefferies himself in a lecture to the Royal Society. The lecture was afterwards published in book form and the Royal Aeronautical Society is fortunate to be in possession of a fine copy of this rare volume.

The aeronauts had an extremely narrow escape from drowning. All ballast, food, ornaments, anchors and ropes, clothing, went overboard from the balloon as it began to come down to the sea. Indeed the two men were making their final preparations for landing on the



BLANCHARD CROSSING THE ENGLISH CHANNEL FROM DOVER WITH AN AMERICAN PASSENGER, DR. JEFFERIES, 1785.



Drawn by T. M. Jones

TO THE WORSHIPFUL THE MAYOR

& CORPORATION OF THE CITY OF BRISTOL.

This PRINT, of the PERILOUS SITUATION of MESSRS. SADLER & CLAYFIELD, who Ascended from BRISTOL on the 24th of Sept.r 1810, at 20 Minutes past 1 O'Clock, and Descended in the BRISTOL CHANNEL, near WATERMOUTH, about 10 Minutes past 4 O'Clock, after passing over upwards of 80 Miles by Water, & 20 by Land in less than 3 Hours,) Is most respectfully dedicated by their devoted and very humble Servant

E. M. Jones.

Published April 25th 1811 by T. M. JONES, 57 & 58 Little Newport Street Newport Market.

JAMES SADLER—THE FIRST ENGLISH AERONAUT.

water, being then only about three-quarters of the way across, when the balloon suddenly began to rise again.

Jefferies, in his description, became positively lyrical about "the pleasing view of France enlarging and opening to us every moment, as we ascended, so as to overlook the high grounds . . . . We now ascended to a much greater height than at any former period of our Voyage . . . . nothing can exceed the beautiful appearance of the villages, fields, roads, villas, etc. under us, after having been two hours over the sea."

The balloon finally landed in the forest of Guines. Blanchard was rewarded with a pension and Dr. Jefferies with undying fame as being the first American to cross the Channel by air, and the first paying passenger to do so. Tourist flights of the present time are cheaper, I believe, for the flight is said to have cost Dr. Jefferies over £700. Luckily we don't have to provide our own aircraft!

The first ascent in England was made by an Italian, Vincenzo Lunardi, who was on the staff of the Neapolitan Ambassador to the Court of St. James'. The balloon rose from the Artillery Ground, Moorfields, on 15th September 1784 (*see* p. 372). The ascent caused the greatest excitement. Many distinguished people of the time were present, including the Prince of Wales and the politicians Pitt, Fox and Burke.

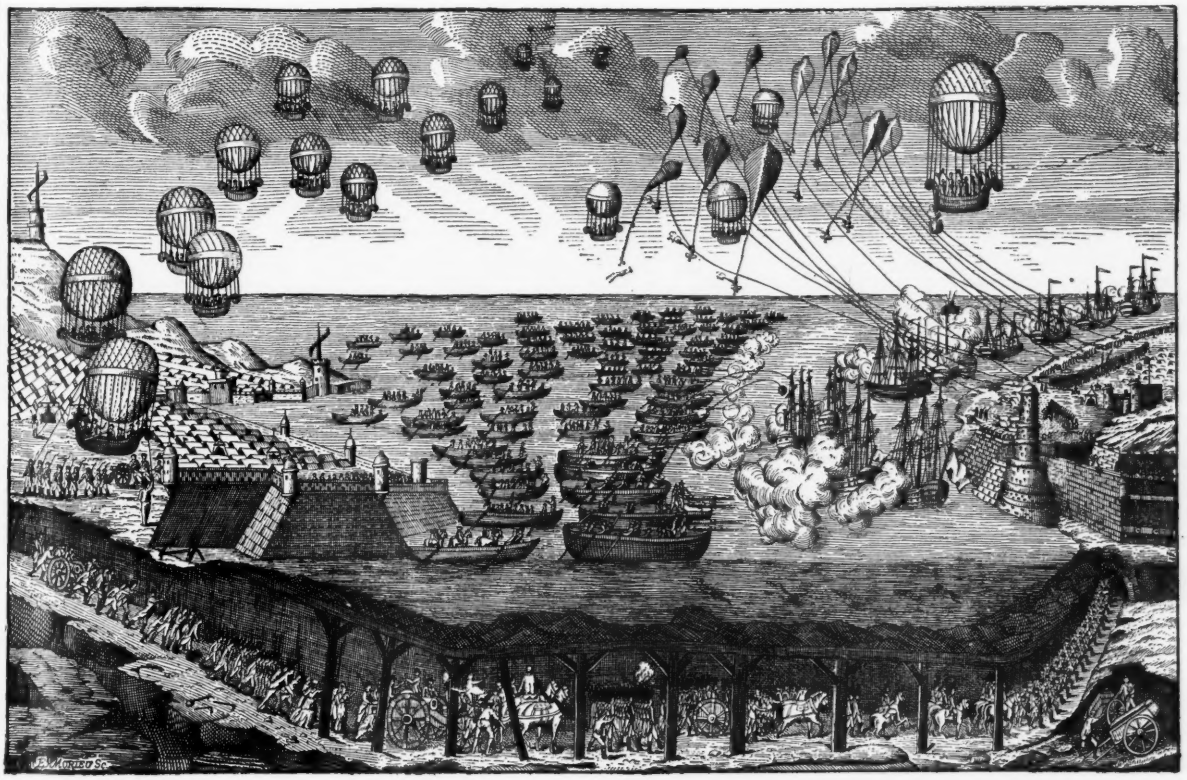
The first time anyone goes up in the air is something they remember, whether the experience is enjoyed or not. Lunardi must have felt more than most the uncertainties of what awaited him, for this was his first balloon voyage and there wasn't a great deal of experience of others upon which he could draw. He took the precaution to make his will and he also took with him his favourite cat and dog, in case he did not come back.

Lunardi had chosen a fine sunny day and the balloon rose about one o'clock. After being in the air for some two and a half hours, it landed near Ware, in Hertfordshire, a distance from the Artillery Ground of some twenty-four miles.

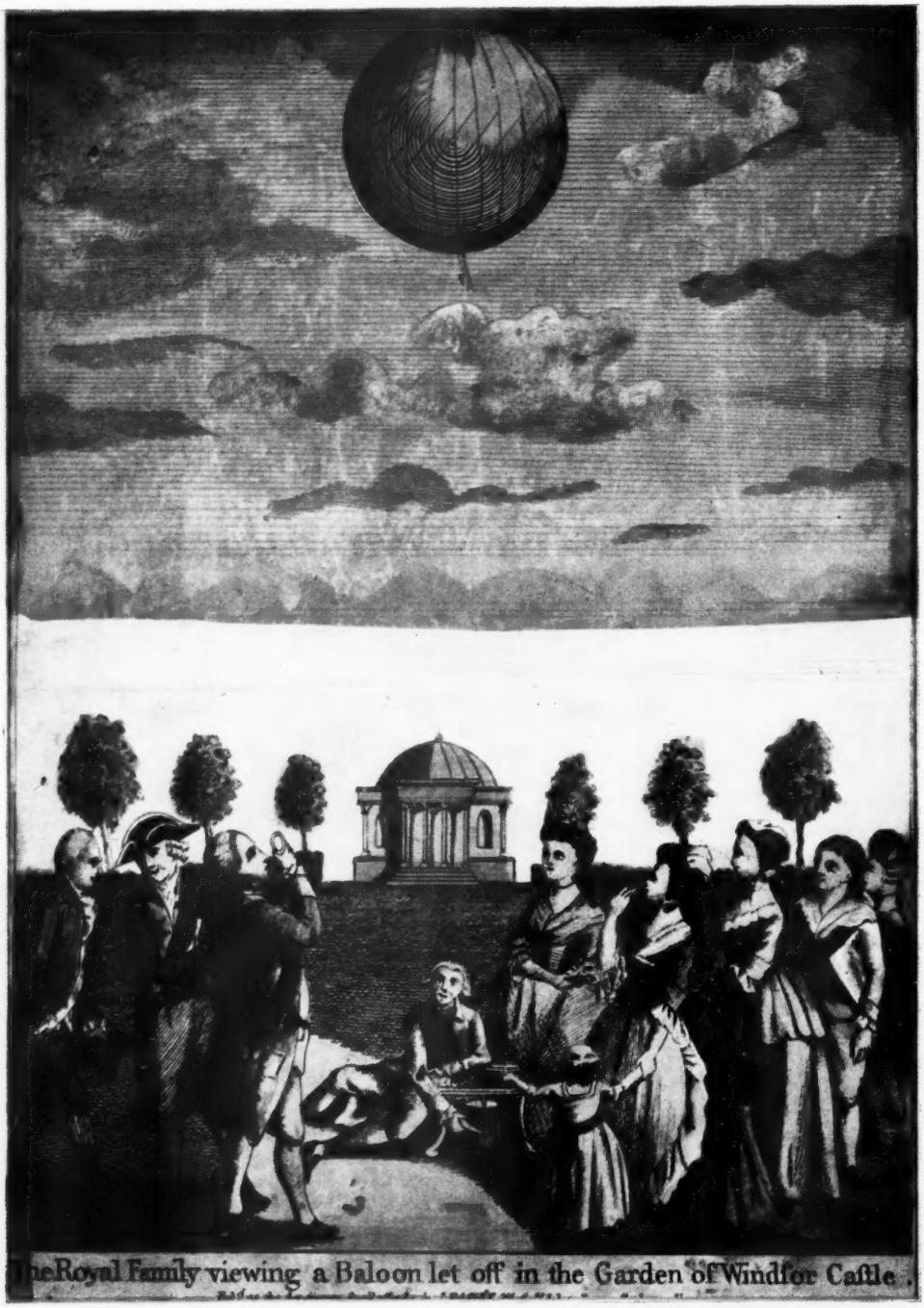
A Lunardi craze followed and it is recorded that Lunardi bonnets and Lunardi garters became the fashion among the ladies of the time. *O tempora! O Mores!*

Although he made numerous ascents in England and on the Continent, Lunardi never understood the dangers of the voyages he undertook, nor had he the ability to find methods of lessening the difficulties of his flights, especially in the technique of landing.

James Sadler was the first English aeronaut, going up in a Montgolfier balloon at Oxford on 9th October 1784. He made a large number of flights in his career and takes his place in English ballooning history with Charles Green and Henry Coxwell. Perhaps his most famous ascent was also his most remarkable and disappointing. On 1st October 1812 his balloon rose from



A PROJECTED INVASION OF ENGLAND—IN 1803.



PROFESSOR ARGAND DEMONSTRATING THE "NEW SENSATION" BEFORE KING GEORGE III AT WINDSOR IN 1784.

Dublin in an attempt to cross the Irish Sea (*see* p. 360). A changing wind first carried him towards the Isle of Man and then over Anglesey, and back again over the sea before he could make a landing. Ultimately the balloon came down in the sea some forty miles off Great Ormes Head and Sadler was rescued by a fishing boat, after having travelled 237 miles over water.

This was not Sadler's first experience of being ditched, to use the modern word. In September 1810 he took up a passenger from Bristol and came down three hours later in the Bristol Channel near Watermouth where they were seen and rescued. A special engraving was made depicting the rescue and presented to the Mayor and Corporation of the City of Bristol in memory of the occasion (*see* p. 356).

The interest in balloons was such that most organisers of entertainment on a large scale used a balloon to attract attention.

Beginning on 1st August 1814 St. James's Park was the scene of a week's high jinks, when the centenary of the House of Brunswick's accession to the English throne was celebrated by those who did and those who did not know what they were celebrating, chiefly the latter one fears. The present picturesque pond was little more than a semi-stagnant canal strip. The diarist Evelyn records that Charles raised a colony of ducks and foreign waterfowl, "I examined the throat of the pelican, a fowl between a stork and a swan, a melancholy waterfowl brought by the Russian Ambassador." One of Charles' pastimes was the feeding of the waterfowl. Charles II made the Park a place of Fashion (sometimes spelt with a small f) for—

"The ladies of St. James's!
They're painted to the eyes,
Their white it stays for ever,
Their red it never dies."

This jubilee week saw a wooden bridge built across the water, with a yellow Chinese pagoda structure raised upon it. Gaily decorated and beflagged marquees along the water's edge allowed those who were not being rowed up and down the canal strip to eat, drink and be merry until the great firework display in the evening (*see* p. 363).

At six o'clock the balloon went up before Buckingham House (now Palace) in the presence of that illustrious Duke of Wellington who was to meet his Waterloo the following year and to become even more illustrious. It was John Sadler's last balloon ascent. The bridge, the pagoda and the trees were illuminated by gaslight, then a complete novelty. At nine o'clock the fireworks started and the pagoda threw out catherine wheels and shooting stars and rockets until itself unintentionally caught fire and added to the general excitement as it finally crashed into the water. John was the eldest son of James.

The first parachute drop was made by the French aeronaut Garnerin in Paris on 22nd October 1797 (*see* p. 364). Garnerin also made the first parachute descent in England on 21st September 1802 from the Volunteer Ground, Grosvenor Square, London. His circular parachute, 23 feet in diameter, had a sustaining surface of 860 square feet. Garnerin cut himself clear from the balloon at a height variously and firmly guessed at from 4,000 to 8,000 feet. The parachute

J. A. C. CHARLES AND ROBERT RETURNING TO PARIS AFTER THE FIRST FLIGHT OF A HYDROGEN-FILLED BALLOON, 1783.

oscillated violently in its fall, but Garnerin, who stood in a cylindrical basket below the parachute, landed safely near the Church of St. Pancras, the first man to suffer from air sickness.

Garnerin's own description of his descent was vivid and amusing. He cut himself loose and just before doing so "I made every necessary disposition, prepared my ballast, and measured with my eye the vast space that separated me from the rest of the human race."

Few words can have been written more descriptive of that last moment of decision.

"I cut the cord. My balloon rose, and I felt myself precipitated with a velocity which was checked by the sudden unfolding of my parachute . . . . I endeavoured to modulate my gravitation, and the oscillation which I experienced increased in proportion as I approached the breeze that blows in the middle region . . . . I came near the earth, and, after one bound I landed and quitted the parachute, without shock or accident."

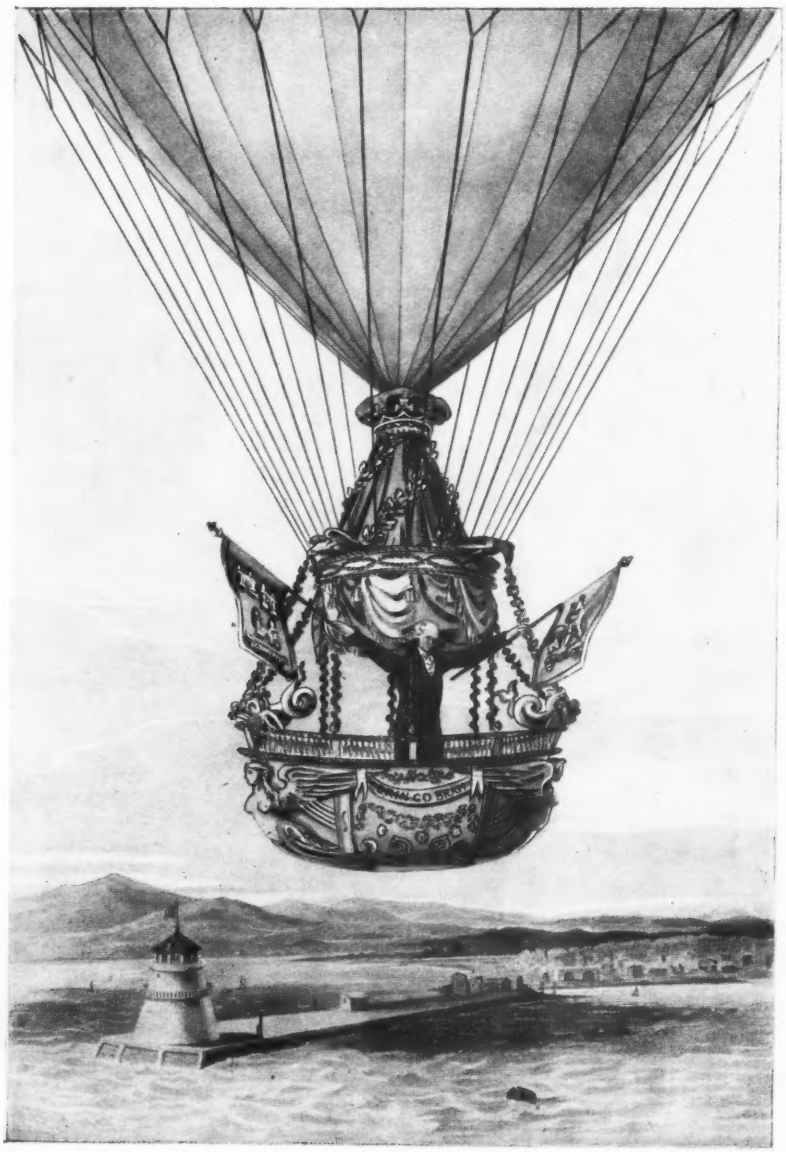
Garnerin's example, which was considered by many as an example of "sublime intrepidity" was not followed in England until thirty-five years later, when Robert Cocking, on 24th July 1837, made his fatal descent from Green's famous Nassau balloon.

Charles Green, to whom reference has just been made, carried out well over 500 balloon ascents and travelled 10,000 miles by air. Born in 1785, his ballooning career began in 1821 and lasted over 30 years.

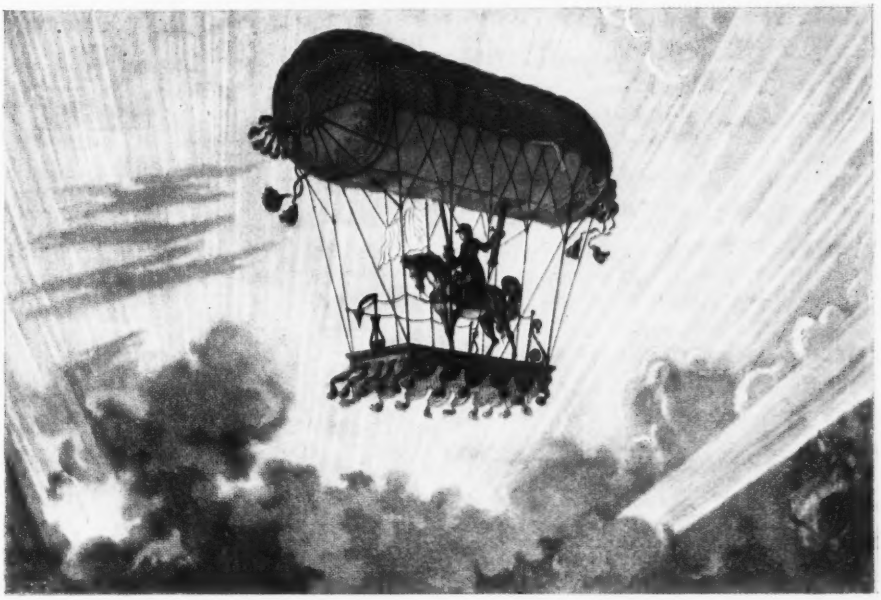
One of Green's earliest flights, it is said indeed to have been his first one, was appropriately enough, by name, from the Green Park, London, at the request of the Government of the day, on the occasion of the festivities in connection with the coronation of King George IV.

The balloon was emblazoned with the Royal Arms and had round it, in large gold letters, "George IV, Royal Coronation Balloon." It rose from the Green Park shortly before one o'clock and descended in a field near Potters Bar at 1.40 p.m. A gusty wind made the descent perilous and Green was forced to hold on to the hoop of his balloon for nearly a quarter of a mile, bumping over the ground, before he regained control. This was the first time coal gas was used for balloon inflation. In those days with no telegraph, telephone or wireless methods of communication, Green sometimes took up a carrier pigeon which he released on landing, bearing a message to his wife that he was safe.

This first ascent by Green coincided with the last official occasion in England when horses entered a banquet hall (*see* p. 353) and got out uneaten, when Lord Howard of Effingham, the Marquess of Anglesey and the Duke of Wellington rode on horseback into Westminster Hall on 19th July 1821 to present the dishes to be eaten by George IV at his Coronation Banquet. Before the second course the King's Champion also rode into the Hall and three times flung down the gauntlet to all comers, while the King drank to the Champion. As they were in the presence of Royalty the riders had to back



SADLER LEAVING DUBLIN ON HIS ATTEMPT TO CROSS THE IRISH SEA, 1812.



ONE OF CHARLES GREEN'S NOVEL WAYS OF AMUSING HIS PUBLIC.

their horses out of the Hall, no mean feat of horsemanship in the circumstances.

That was the last Coronation Banquet to be held in Westminster Hall, and the most sumptuous of a long series of banquets going back to the time of William Rufus. The Hall was lighted by some two thousand candles "suspended in magnificent lustres suspended by gold chains from the angels in the roof." The hot wax dripped down on the robes of the peers and peeresses, and tempers rose with the dripping, for none could move until the banquet was over.

Green used the Coronation balloon for some five years. He advertised it as being 107 feet in circumference with a capacity of 136,280 gallons of gas.

Green's hundredth ascent was made from the Mermaid Tavern at Hackney on 14th May 1832. As with all new attractions Green had been forced to do more than just make balloon flights to attract the public. On occasion he dropped animals by parachute from the balloon, and risked his life by ascending at night and giving a firework display. He even replaced the balloon car with a pony and rode on its back into the skies. It reminds one that pigs did not fly until Lord Brabazon took one up in his aeroplane in 1909. It was not uncommon in those early ballooning days to see a horse fly, and the sight may have inspired Wordsworth when he wrote those opening lines of Peter Bell,

> "There's something in a flying horse,
> There's something in a huge balloon;
> But through the clouds I'll never float
> Until I have a little Boat,
> Shaped like the crescent moon."

Peter Bell must have had a far-seeing eye for the crescent wing did not make its appearance until another Queen was on the throne of England!

Green was the most successful aeronaut of his day, so successful indeed that the proprietors of the Vauxhall Gardens in London financed the building of a considerably larger balloon than the Coronation. At that time there were many Pleasure Gardens round London, competing with one another. It was in the Adam and Eve Tea Gardens in the Tottenham Court Road that Lunardi made the first forced landing in this country from the air, on 13th May 1785. Vauxhall Gardens and Cremorne Gardens saw many ascents by Charles Green, and the Hodgson-Cuthbert Collection contains over a hundred and sixty posters advertising one or other of these Gardens and balloon trips from them by Charles Green, as well as many other balloon posters. On one occasion Green rose from Cremorne Gardens accompanied by a lady and a leopard, but history does not record whether it was the lady or the leopard which smiled when they came back from the ride or whether the leopard's amber eyes turned to Green.

Of his firework displays an advertisement of the time declared that "the intrepid Aeronaut, Mr. Green, will make his second ascent from these Gardens at ten o'clock at night in his baloon! with the car magnificently illuminated!" They spelt baloon that way in those days when they felt like introducing nu spelin.

Green was a friend of W. H. Wenham and James Glaisher, both original members of the 1866 Council of the Society. With Glaisher, Green made a number of scientific balloon ascents for the British Association, reaching a height on one occasion of 23,000 feet.

The most famous of all Green's voyages was that from London to Nassau, accompanied by Mr. Hollond and Mr. Monck Mason. The three travelled from Vauxhall Gardens to Weilburg in Nassau, a distance of 480 miles, in November 1836. Nassau is now in Germany, which at that time did not exist. Hollond, a member of Parliament who had made a number of balloon voyages, was responsible for the idea and expenses of this particular voyage, undertaken to test the use of the

trailing rope for controlling the height of balloons and so saving the use of too much ballast. He became an original founder member of the Society in 1866. The pompous Monck Mason was interested in the Theatre and knew more about opera than aeronautics but that did not prevent him from writing a book *Aeronautica* describing his balloon experiences.

The balloon went *via* Dover across to Calais (the first *all British* aerial crossing of the *English* Channel), Ypres, Lille, Brussels, Namur, Liège, across the Rhone to Coblentz, and landed in a field eight miles from Weilburg, 480 miles in 18 hours. It was not until 1907 that the record from England was beaten, when C. C. Turner, who only died this year, a member of the Society, went from London to Sweden by balloon.

The Vauxhall Balloon was 157 feet in diameter and 70,000 cu. ft. in capacity and was stated to be capable of lifting 28 people of an average weight of 140 lb. each. There was no rationing in those days evidently.

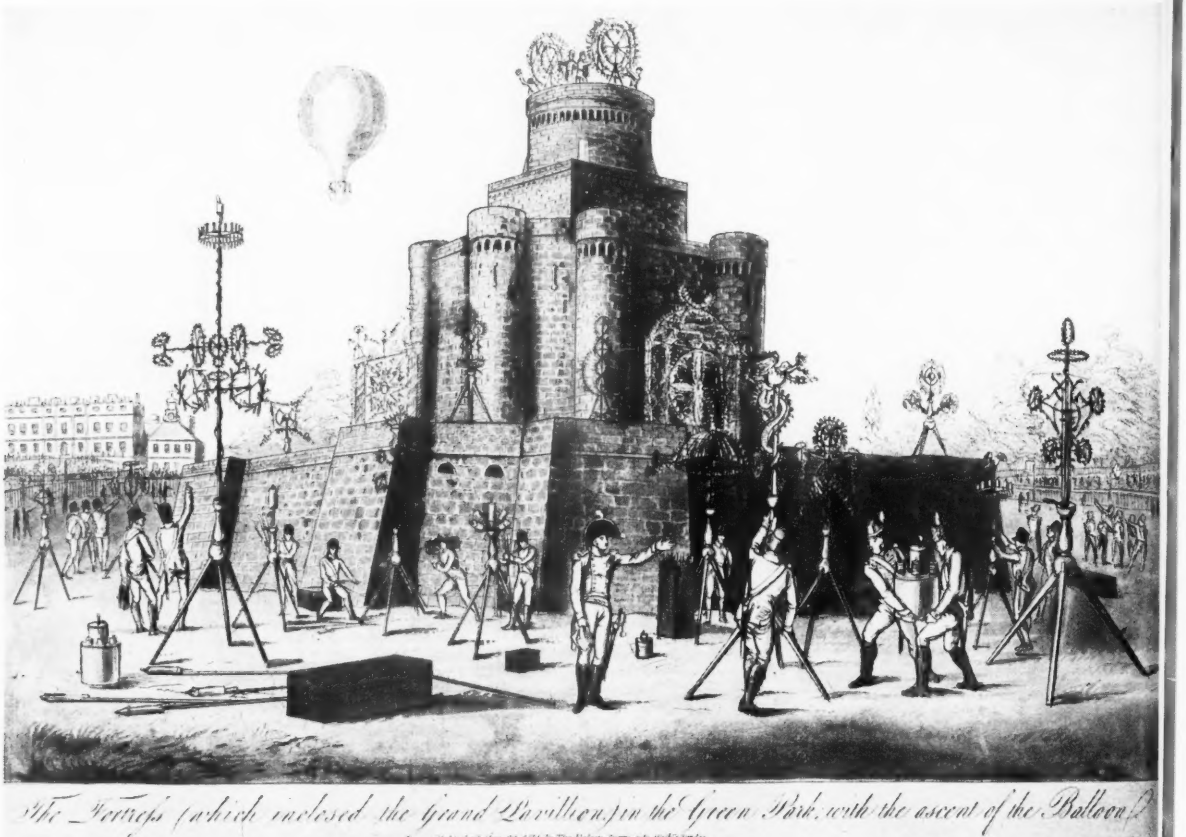
The voyage created a great sensation, and the story of it reached lasting fame when *The Monstre Balloon* was published in the immortal Ingoldsby Legends.

"Oh! the balloon, the great balloon
It left Vauxhall one Monday at noon,
And everyone said we should hear of it soon
With news from Aleppo or Scanderoon.
But very soon after folks changed their tune:
'The netting had burst—the silk—the shalloon;
It had met with a trade wind—a deuced monsoon—
It was blown out to sea—it was blown to the moon—
They ought to have put off their journey till June;
Sure none but a donkey, a goose, or baboon
Would go up in November in any balloon!'"

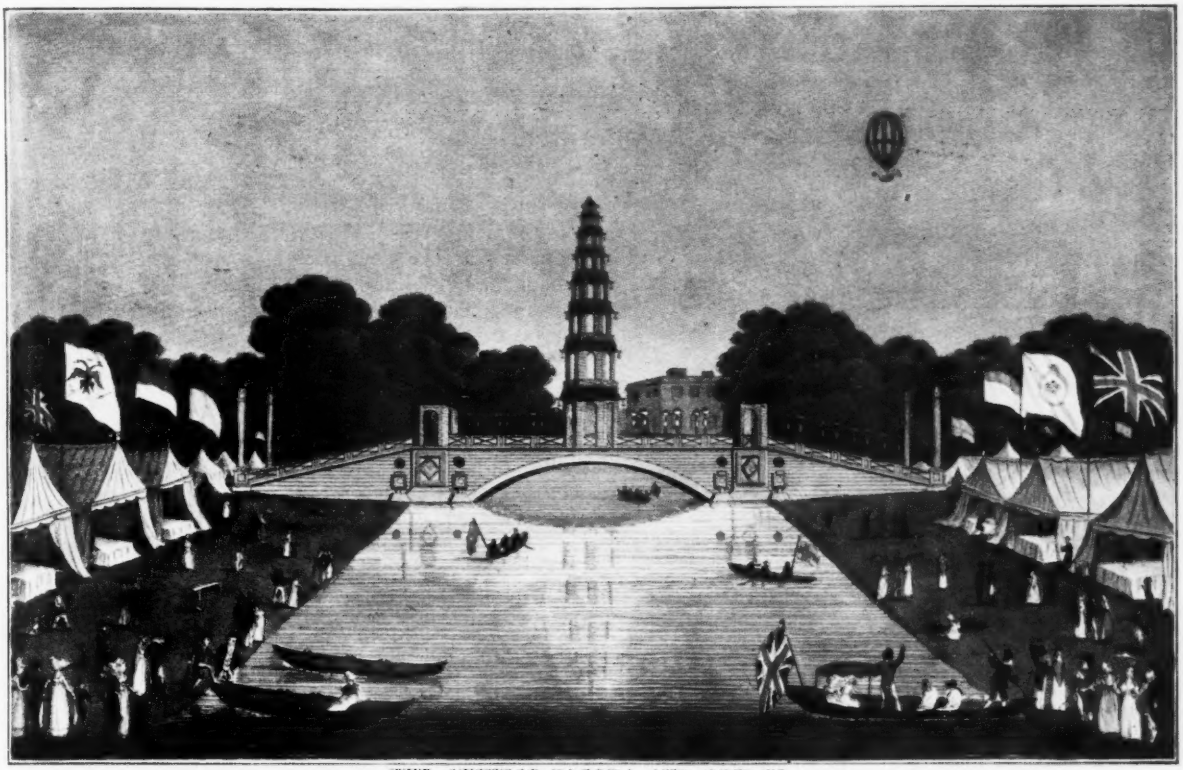
Thomas Ingoldsby (né Barham) was echoing the many rumours which flew about as the balloon flew out of sight. I wonder sometimes if he had a secret television, for later on he writes,

"And there, on a beautiful transparent screen
In the middle you'll see a large picture of Green,
Mr. Hollond on one side, who hired the machine,
Mr. Mason on t'other, describing the scene."

A copy of Monck Mason's "Account of the Aeronautical Expedition of the Great Balloon" was specially



The Fortress which inclosed the Grand Pavilion in the Green Park, with the ascent of the Balloon.



THE CHINESE PAGODA AND BRIDGE,
erected over the Canal in St James's Park, for the Grand Jubilee of the 1st of August 1814.
Published Sept^r 1, 1814 by JAMES WHITTLE & RICHARD HOLMES LAURIE N°53 Fleet Street London.

prepared for Hollond. It was taken to pieces and mounted on large folio sheets with a number of extra illustrations and is, of course, a unique copy, now in the possession of Lt.-Col. Lockwood Marsh, a former Secretary of the Society.

On page 370 is a copy of the passport issued to Green and his companions, the first air passport from London to the Continent, probably the first air passport in the world, and now in the possession of the Society.

Many ideas were put forward for guiding balloons, so that they were not so dependent upon every wind which blew. Sir George Cayley had, in the first decade of the nineteenth century, laid down the general principles of the dirigible, but many who had read of his proposals had little or none of the engineering knowledge to understand what they were reading.

One of the most futile of these early projects from an airship point of view, but not quite so futile from the financial point of view of obtaining money from a lighter-headed public, was that of the "Aerial Ship The Eagle," particulars of which appeared in June 1835 in the London newspapers. Under the heading "European Aeronautical Society" it was announced that the first aerial ship, 160 feet long, 50 feet high, and 40 feet wide, manned by a crew of 17, would be constructed for establishing direct communications between the several capitals of Europe, the first flight to be made on the inevitable London to Paris route.

> "In London you may breakfast take,
> And, as she no where tarries,
> The Eagle will such progress make,
> That you may dine in Paris."

said the poetaster of the time.

The ship was placed on exhibition in Kensington and a large number of visitors paid a shilling a time to look at it. When the public lost interest and shillings became fewer or were wanted for the gas with which the ship was not filled, the promoters slowly and silently vanished away and the Aerial Ship was never launched.

The Hodgson-Cuthbert Collection contains many engravings, drawings, cartoons and contemporary descriptions of navigable balloons, most of which were more fantastic in their conception than in the claims for their possible achievements. The first flights of the Montgolfier and Charles balloons had hardly been made in 1783 than Thomas Martyn, in November 1783, sent to the Prince of Wales a design for an aerostatic globe. It was the earliest English design and the worst. As late as 1835 another undoubting Thomas, Thomas Mackintosh, published a drawing of his Aerial Ship drawn by sixteen trained eagles. Samuel Pauly and Durs Egg in 1816 produced a fish-shaped balloon only a little

GARNERIN AND HIS PARACHUTE.

less fantastic than their names, and were followed by other inventors with plausible schemes and pleasable shapes. In the very year the Society was founded, 1866, Richard Boyman took out a patent for the construction of a cylindrical balloon, made of steel, a quarter of a mile in length and weighing 600 tons!

Pray silence for the next sentence.

The inventor proposed to use jet propulsion as the motive power!

The Society certainly chose a good year in which to start and put forward ideas for the future!

In these too modern days, on high days and holidays, on days of triumphal arches, of fanfares, of ovations and jubilees and of coronations, there are fly pasts, "that's a jet that *was*." In those days when the eyesight was so good that, "that's a balloon that *is*," the balloons went up from the Pleasure Gardens, from the great open spaces and parks, when festive crowds gathered to rejoice, from the palaces of the kings and the queens. Coronation times were indeed special occasions and the balloons had a majesty and serenity about them no jazzing jet will ever have, fly she never so fast.

Garnerin, who made the first parachute drop, was known in France as "Aerostier des Fêtes Publique" and was appointed to arrange an aeronautical display on the occasion of the coronation of Napoleon on 3rd December 1804 (*see* p. 369). Garnerin constructed five decorated hydrogen balloons. None was intended to carry passengers, but one had suspended from it a symbolic laurel wreath. The story ran at the time that the balloon had been carried over the Alps by the wind and the royal laurel wreath had fallen on Nero's tomb, a story which so angered Napoleon that Garnerin fell into disgrace.

Mention has already been made of the Coronation balloon in which Green rose during the official festivities on the occasion of the Coronation of George IV.

When Queen Victoria was crowned on 28th June 1838, the whole country and many balloons rose to the occasion. From Hyde Park in London to Parker's Piece in Cambridge festivities on the grand scale were held. Coronations of young queens have an attractiveness which only comes from the rare combination of youth and beauty and high position.

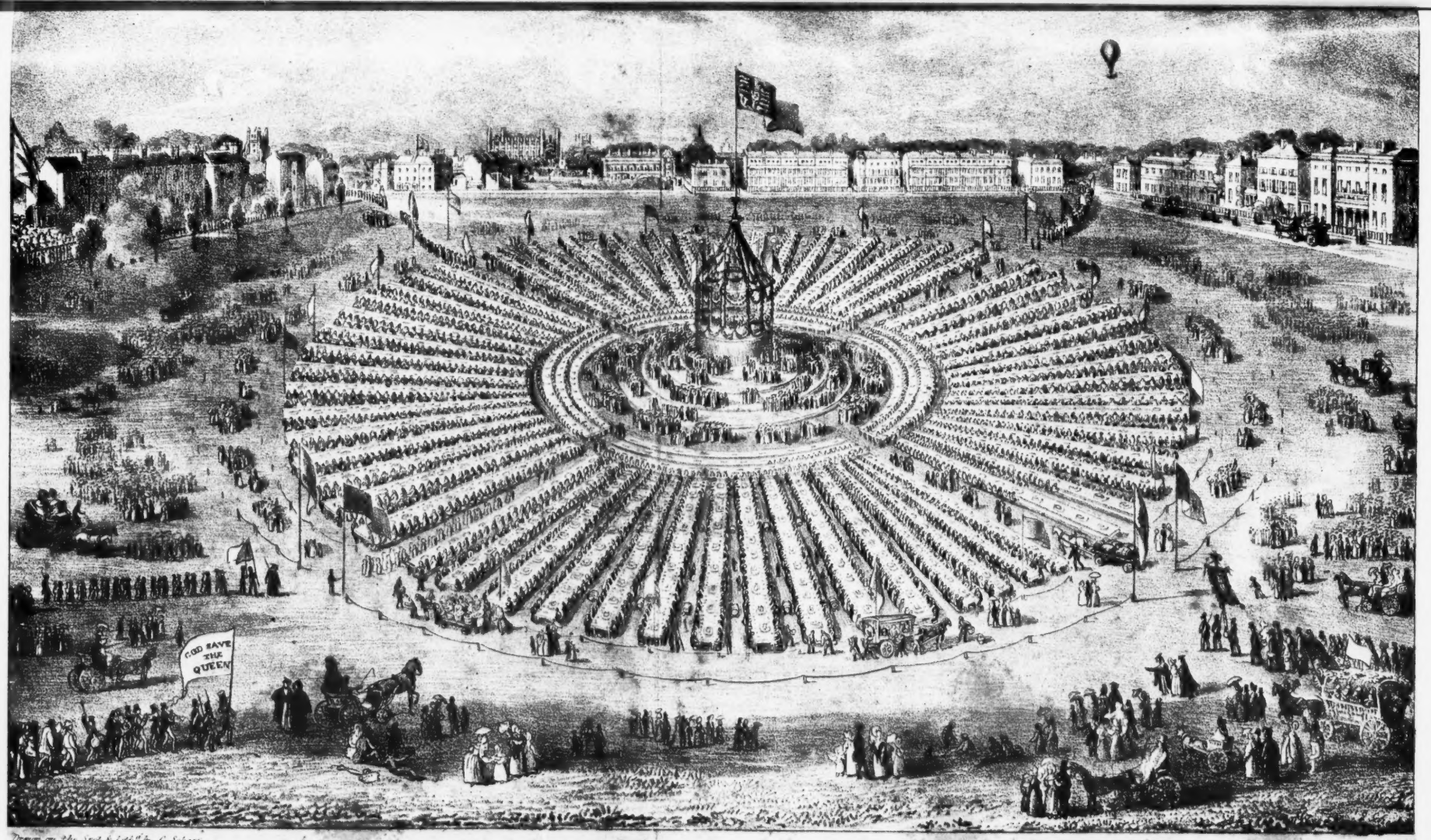
There was a great fair held in Hyde Park at Coronation time (*see* p. 368) and the famous Mrs. Graham made a balloon flight from the Green Park near by as part of the official Government festivities. Mrs. Graham was as well known as her husband as a balloon pilot. I quote a letter she wrote in August 1836, "At the Coronation of their present Most Gracious Majesties, on the 8th of Sept. 1830, I had the honour of ascending in their presence from Green Park, and made a most successful descent on the estate of Lord Peters, near Brentwood, in Essex. Upon this occasion their Majesties were graciously pleased to appoint me by special order their Aeronaut."

Perhaps the day is not far distant when the Captain of the Queen's Flight may be appointed from the gentler ranks of those who serve her.

Mrs. Graham's balloon flight on Queen Victoria's Coronation day was unfortunately marred by an accident when the grapnel from the balloon tore a coping stone from a house in Marylebone, and a passer by was killed. Once Mrs. Graham took up royalty itself, His Serene Highness the Duke of Brunswick. The landing was a bit more bumpy than usual and a wag of the time wrote,

> "When Brunswick's Duke ascended high,
> He felt a little queer, I ween.
> His Highness, true—when in the sky,
> Was not, I fancy, quite serene."

Perhaps the most astounding of all the festivities of Queen Victoria's Coronation was when the balloon went up and the food and drink went down on Parker's Piece, Cambridge. For those who have never heard of Parker's Piece (mostly living in Oxford, I fear) it is perhaps one of the better open spaces, for it was there that the famous Tom Hayward and the still more famous Jack Hobbs learnt to play cricket.



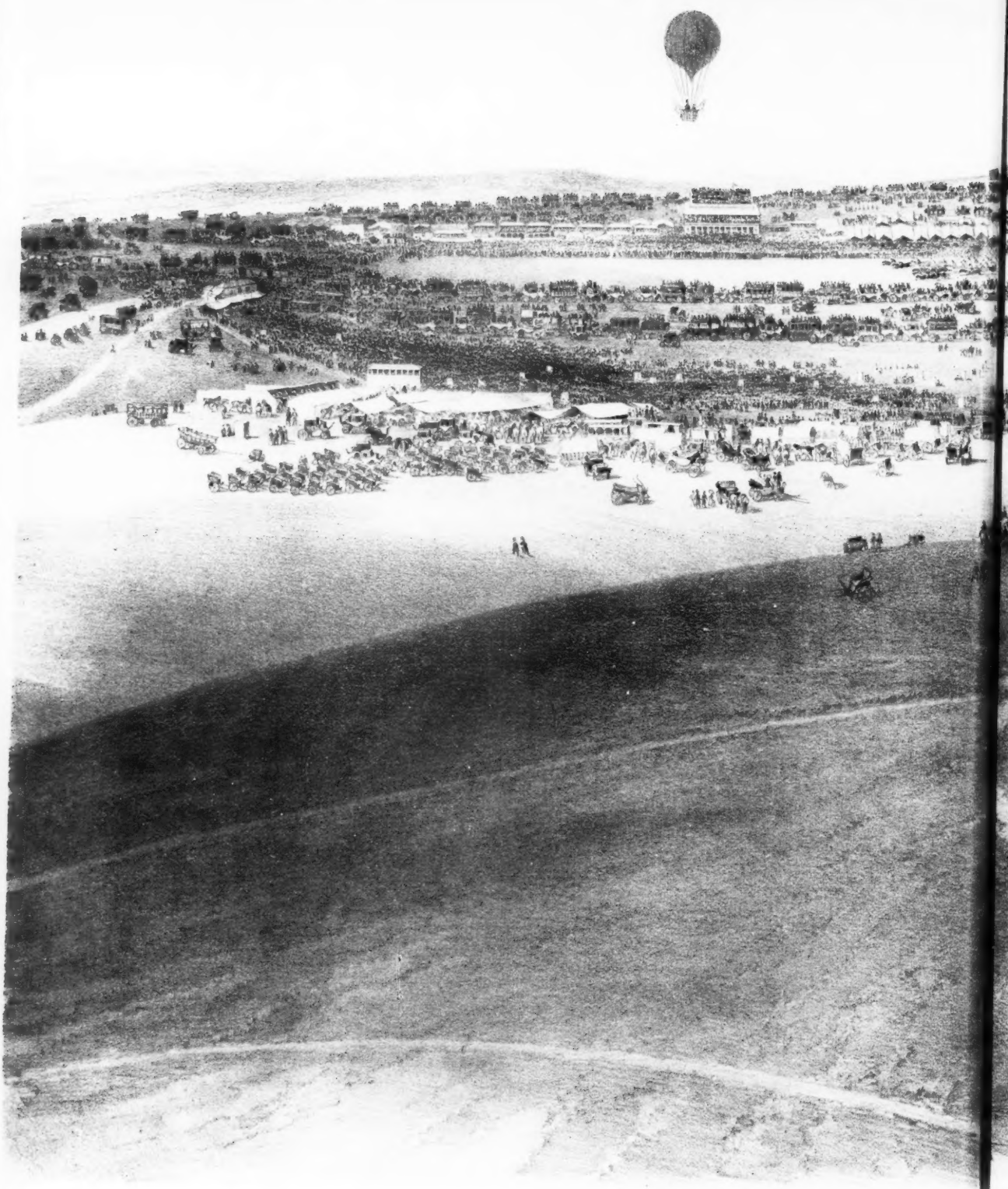
Drawn on the Spot & Lith.d by C. Schurr

Metcalfe & Palmer, Lithog. Cambridge

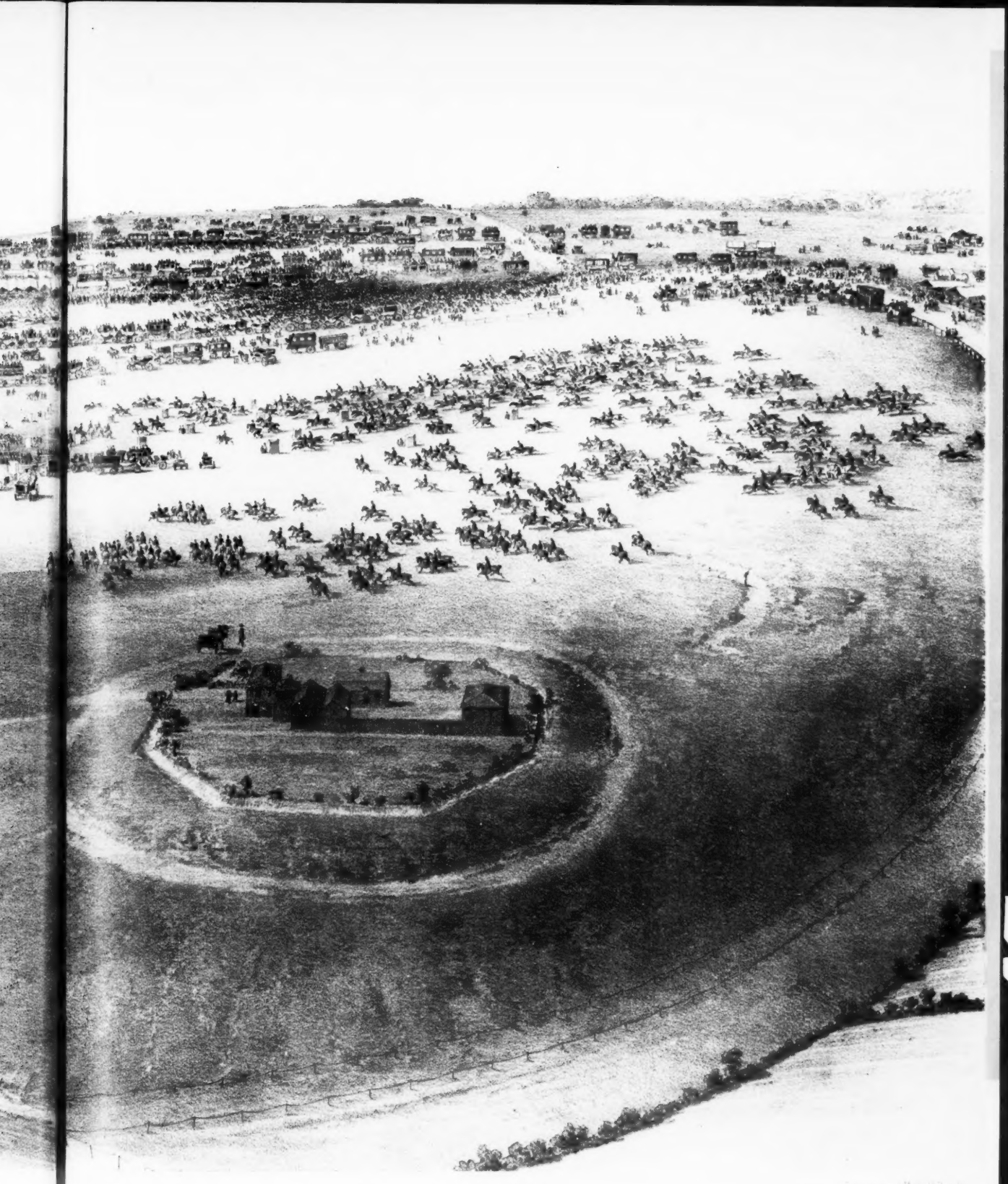
A VIEW of the GRAND FÊTE on PARKER'S PIECE, CAMBRIDGE;

To celebrate the Coronation of HER MOST GRACIOUS MAJESTY QUEEN VICTORIA. June 28th 1838

Number of Persons seated to Dinner 15,000, *supposed number of Spectators* 17,000. *TOTAL number present* 32,000.



A VIEW FROM A BALLOON OF EPSOM RACES



M RACES DERBY WAS WON THAT YEAR BY MR. GULLY'S PYRRHUS I.

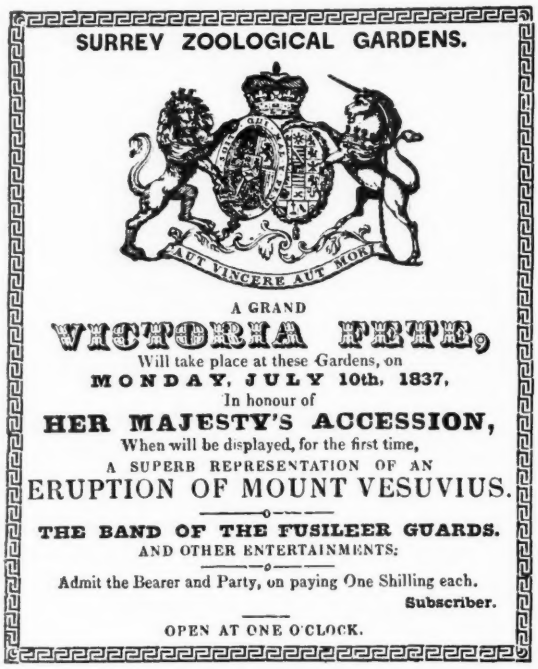
Parker's Piece was named after a humble cook to whom Trinity College leased the land in 1587. In the early days of the nineteenth century it became the centre of many of the Cambridge festivities, political and other parades and general occasions of rejoicing. But never before nor since has the old cook's Piece seen such an astonishing sight as it did on the day Queen Victoria was crowned.

For upon that day fifteen thousand people sat down to dinner, while seventeen thousand envious spectators watched. The tables were arranged along the spokes of a giant wheel, with circular tables in the centre forming the hub. The fifteen thousand who sat down were more than half the total population of Cambridge at the time, and included three thousand children.

Indeed the local newspaper reported that "there appeared to be many whole streets without a single individual in them—we mean even in the houses."

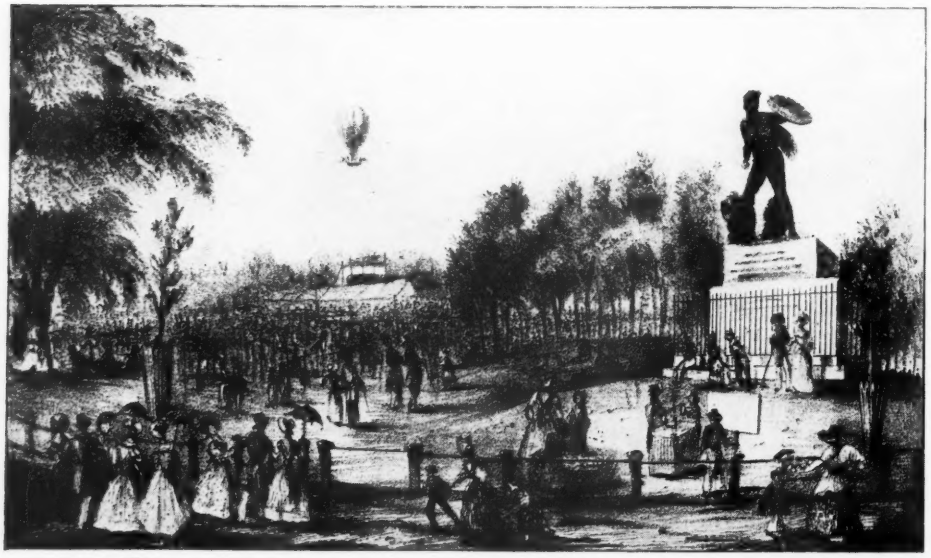
It was a warm sunny day and the *Independent Press* reporter wrote, "All nature seemed to sympathise with the joyous occasion . . . . All the ordinary occupations of daily life were suspended, shops closed, houses deserted, streets crowded with dense masses of people, all wending their way to one grand point."

And what did they eat? Believe it or not they ate on that day 1,608 plum puddings, weighing 10,452 lb.; 14,182 lb. of beef; 72 lb. of mustard; 140 lb. of salt; 125 gallons of pickles; 9,000 lb. of bread, 28,500 pints of the best ale; 100 lb. of tobacco; 6 lb. of snuff. Every man had three pints, every woman one pint, and every child half a pint of best ale.


SURREY ZOOLOGICAL GARDENS.
AUT VINCERE AUT MORI
A GRAND
VICTORIA FETE,
Will take place at these Gardens, on
MONDAY, JULY 10th, 1837,
In honour of
HER MAJESTY'S ACCESSION,
When will be displayed, for the first time,
A SUPERB REPRESENTATION OF AN
ERUPTION OF MOUNT VESUVIUS.
THE BAND OF THE FUSILEER GUARDS.
AND OTHER ENTERTAINMENTS:
Admit the Bearer and Party, on paying One Shilling each.
Subscriber.
OPEN AT ONE O'CLOCK.

AN EXAMPLE OF ONE OF THE MANY POSTERS FROM THE HODGSON-CUTHBERT COLLECTION (*above*).

(*Below*): MRS. GRAHAM'S BALLOON IN FLIGHT AT A FAIR IN HYDE PARK ON 28TH JUNE 1838 WITH THE STATUE OF ACHILLES (ERECTED TO THE DUKE OF WELLINGTON IN 1822). ALL THE IMPRESSIONS OF THIS PRINT WERE STRUCK OFF IN THE PARK, THE STONE HAVING BEEN TOTALLY DESTROYED (BY THE EXCESSIVE HEAT OF THE WEATHER) BEFORE THE CLOSING OF THE FAIR.



View of the Fair in Hyde Park.
Printed in the Park on June 28th 1838

Dinner started at two o'clock and, said the official report, "to the meat succeeded a supply of plum puddings as never had been witnessed in this kingdom before," nor since—well, at any rate since rationing began.

I have had a long experience of Committees of all sorts of ideas and sizes, and believed in consequence that they were a monstrous growth of democracy's fear of responsibility. But I publicly and gratefully declare that I found myself completely mistaken when I read the reports of the nineteen committees appointed to organise the festivities on Parker's Piece.

There was one with the title "Committee of Taste for the choice of a design for the dinner ticket."

The design being settled another committee was formed, the Dinner Ticket committee, to report on how the tickets were to be distributed, and a third committee whose title is self-explanatory of its function, "Committee for fixing the price of spectators tickets."

There were a Table Cloth Committee, a Committee of Arrangements for the singing of the Graces and the National Anthem, separate committees for the provision of the Meat, Bread, Beer, Snuff and Tobacco consumed, and, of course, the Pudding Committee! The Pudding Committee recommended 2,470 lb. of raisins, 825 lb. of suet, 3,300 eggs, 10 sacks of the finest flour, and 360 gallons of milk.

Most of the Cambridge college kitchens were boiling puddings and roasting meat. Some 400 of the puddings, however, were boiled in the local brewery, and I dare say they went down well with those lucky to get a portion.

But it was the Balloon Committee which provided the final excitement of that Cambridge Coronation Carnival. The great aeronaut, Charles Green, was engaged "for the amusement of the company. At half-past six, all things being ready for the ascent, he, accompanied by his fearless consort (Mrs. Green), entered the car . . . . The lady turned round in the car, and looking fearlessly down, continued to wave a handkerchief until the elevation reached by the balloon rendered her and her companion invisible to mortal sight."

Green and his wife became visible again at 20 minutes to 8 in a field near Fulbourn, about seven miles from Cambridge.

On the occasion of the Coronation of Edward VII Parker's Piece was again a scene of festivity when 6,000 schoolchildren were entertained to tea. The fact is recorded in the Society's archives, and appropriately, should be recorded here, for one of the children was a W. Farren, now, in the Coronation Year of Elizabeth II, Sir William Farren, President of the Royal Aeronautical Society.

I like to read the contemporary descriptions of what happened in those days of long ago. John Cuthbert collected so many interesting accounts. This Coronation year many people will firmly believe that never has there been such a sight as the Coronation procession, with the flags and the emblems and the bands and the guns and the uniforms.

GARNERIN'S DECORATED BALLOON WITH THE LAUREL WREATH AT NAPOLEON'S CORONATION, 1804.

783

AVEC L'AUTORISATION de SA MAJESTÉ le ROI,

des PAYS-BAS, Prince d'Orange - Nassau Grand Duc

de Luxembourg, etc. etc. etc.

Le soussigné Consul general de la dite Majesté dans la Grande

Bretagne Chevalier de son ordre du Lion.

Prie M.M. les Officiers Civils, et Militaires.

de laisser passer librement

Monsieur Charles Green aeronaute Anglais

accompagné de Monsieur Holland

& de Monsieur Monck Mason

sujets d'Angleterre

demeurant a Londres

allant aux Pays-Bas en Ballon

et de lui donner aide et protection en cas de besoin

Valable pour
Six mois

Signalement

Age de Trente

taille Cinq pieds pouces

Signature du Porteur

Robt Holland

Fait à Londres, le 2 Novembre 1836

Le Consul general

J. W. May.

THE PASSPORT ISSUED TO GREEN, HOLLOND AND MONCK MASON FOR THEIR FLIGHT FROM LONDON TO NASSAU IN 1836.

Just seven years before Queen Victoria was crowned, King William and Queen Adelaide opened the new London Bridge and the famous Charles Green went up in his Coronation balloon (*see* p. 373). It is interesting to reprint here the general account of the proposed arrangements, as published by posters announcing the opening of the Bridge.

"The Royal tent is to be pitched at the London side of the Bridge, near to the place on which Fishmonger's Hall stood, and will command an unobstructed view of the whole line of road to the Southwark side. The Royal table will be laid for about twenty persons. On the left of it, extending to one of the entrances from Thames Street, will be laid two tables for the noble persons who will accompany their Majesties. One of these tables will be laid for 68, the other for 76 individuals. A large space will be left open at the right of the Royal tent, it being the intention of their Majesties to disembark at the Grand Wharf on the right of the Bridge: and the Committee having appointed that the procession shall go forward from that spot the moment their Majesties land. A double row of tables will be ranged, on each side of the wide space through which the procession is to pass, for the accommodation of the other visitors, who are to be admitted, if we may judge from the present appearance of the arrangements, to the number of 1,560. The awning, which is to be placed over the long table, will extend to the length of about 400 feet: there are to be three roofs to the large awning, so that the company will be as effectually secured against bad weather as if they were to be shut up in the Guildhall, which the art of man could never make worthy of a comparison with the scene which will be presented on the 1st August on London Bridge, the river, and in the surrounding neighbourhood. Flags and colours, with emblems and devises, will wave above the heads of the company, and cannon will be fired at intervals. Bands of music will, in various parts of the arena perform during the ceremony, and every thing that can contribute to render the spectacle delightful to the public will be done,

PART OF ONE OF THE HAND COLOURED RICE PAPER PRINTS BOUGHT IN THE NATIVE BAZAAR AT HOWRAH IN 1853.

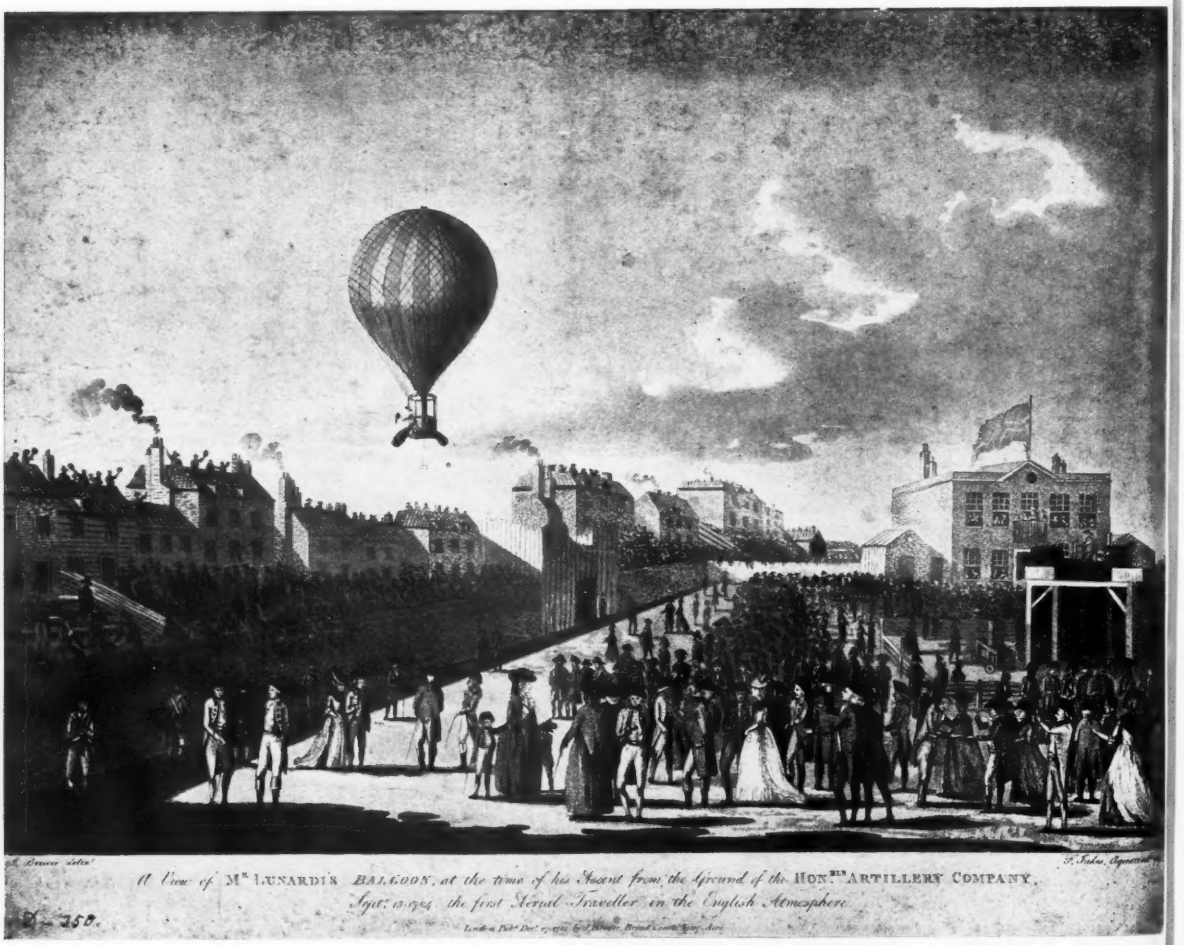
at least so far as the Committee may be able to satisfy the public curiosity. The works on the Bridge are superintended by Mr. Montague, the Clerk of Works.

"The Lord Mayor has given up the authority over the river for the day of the ceremony to Sir Byam Martin, and the arrangements on the water are to be under the direction of Mr. George Ledwell Taylor, the Surveyor to the Navy. Their Majesties are to go on board the Royal barge at Somerset House at three o'clock in the afternoon, and the procession on the Thames is to be as follows:—First advances the Trinity barge, next the Victualling Board barge, and then follow in order the Navy Board barge, the Treasurer of the Navy's barge, the Board of Ordnance barge, the Commander-in-Chief of the Army's barge, the Admiralty barge, the Lords of the Treasury barge, the Royal Family's barge, the barge of the Lords and others in attendance upon his Majesty.

"From Somerset House to London Bridge barges splendidly decorated will be moored on each side of the river, and between the barges so moored, room will be left for the small boats, so that immense numbers of persons will be enabled to see the water procession, which it is expected, will be infinitely more grand, as it will be infinitely more extensive than the procession on the bridge. The barges of all the Companies will be ranged near the bridge, splendidly decorated. The river will, during the whole ceremony, present the most brilliant exhibition. Not a vessel or boat will be seen to move in the line of the procession, with the exception of those which are to perform the procession itself. In the barges moored along the line of procession, seats are to be fixed one above another for the accommodation of the public.

"Barriers are to be fixed at Fishstreet-hill, at Little East-cheap, Gracechurch-street, in Cannon-street, in Mile's-lane, and in Upper Thames-street.

"The Thames Police are to take their station on the river to prevent accidents. It has not yet been determined in what dress the Corporation are to receive their Majesties, but it is supposed that the Lord Mayor and Aldermen will appear in their robes, and the Members of the Court of Common Council in their gowns."


A View of Mr. LUNARDI'S BALLOON, at the time of his Ascent from the Ground of the HON.BLE ARTILLERY COMPANY,
Sept.r 15.1784 the first Aerial Traveller in the English Atmosphere

THE FIRST BALLOON ASCENT TO BE MADE IN ENGLAND—BY LUNARDI IN 1784.

1 Lords in Attendance
2 Royal Family
3 Royal Barge
4 Earl Grey & Ministers
5 Lords Commissioners of the Admiralty
6 Secty of State &c

7 Gen.l Comd.r of the Army
8 Ma.r Gen.l of the Ordnance
9 Comd.r in Chief of H.M. Ships
10 Treas.r of the Navy
11 Navy Off.r Boat
12 Commiss.rs of the Navy

THE OPENING OF NEW LONDON BRIDGE
by their most Gracious Majesties William the 4th & Queen Adelaide

London Published by R Havell 77, Oxford St.

By this time you may well ask, after being told so much about the balloonatics, weren't there any aeronautics? Yes, there were, and Cuthbert collected information about their ideas. I refrain from quoting the work of Sir George Cayley as this has been the subject of several papers already in the JOURNAL. Suffice to say he was such an outstanding figure in the early history of aeronautics that tribute to that fact has often been paid to him by leading authorities in the new and the old world.

That outstanding figure in American aeronautics, Jerome C. Hunsaker, declared in the Terry Lectures read before Yale University in 1951,

"The aeroplane as a structure was described in 1809 by Sir George Cayley, who explained how to make a surface support a weight by the application of power to the resistance of the air . . . . In 1842 Henson, another Englishman, patented a monoplane with a steam engine, and provided vertical and horizontal rudders to steer it. After Cayley, Henson, as nearly as any one person, foretold the flying machine. All essential elements were disclosed except means for lateral control."

Nothing could be fairer than that. Cuthbert added all the details he could find to the efforts of Henson to fly, including the embroideries of an excited but otherwise dull press.

William Henson's 1842 patent was for a "machine for conveying letters, goods and passengers from place to place through the air." His ideas were unfortunately exploited before any real experiments had been carried out. Early in 1843 Company promotors sought Parliamentary powers for an Aerial Steam Transit Company based on the patent, and the public were invited to subscribe. Many descriptions were given of Henson's Aerial Steam Carriage and highly specious accounts were put forward of passenger flights. *The Times* itself was hoaxed into publishing an account of an "experimental Trip on an Aerial Machine" by Professor Geolls.

Henson made several models, driven by a small steam engine or a spring, which he showed in London under pressure from the exploiting company in 1843. It was not, however, until Henson and Stringfellow formed their own partnership and experimented at Chard in Somerset that the first successful flying model was made.

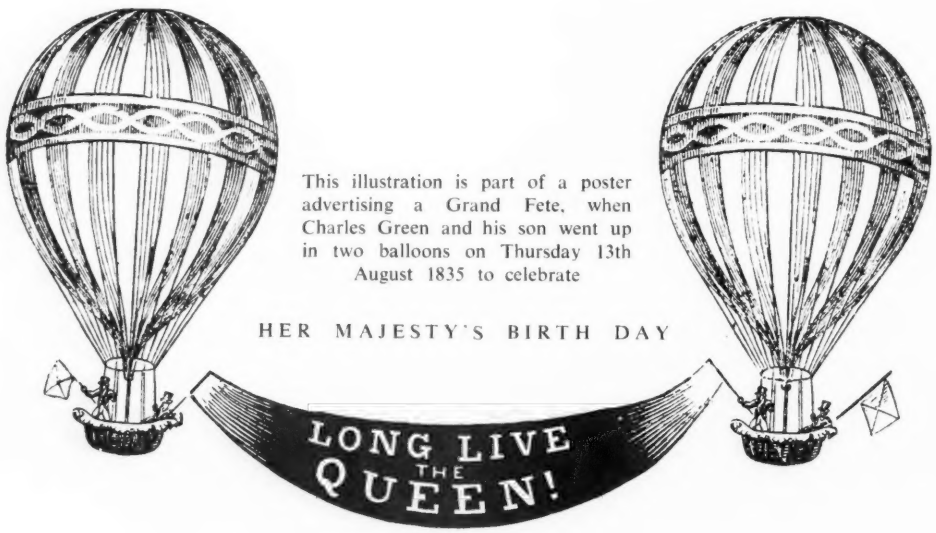
Many engravings and coloured prints were published at the time showing the Aerial Steam Carriage in full flight over London, the Pyramids and China, and a number of these are to be found in the present collection.

The foregoing is an all too brief account of the ever recurring interest which is aroused every time one turns to the Collection. There are many beautiful and rare coloured plates, and many curious pictures the stories about which are still to be written. For example, in April 1853, a Mr. Fitzpatrick Kight, according to a handwritten note on the picture reproduced on page 371, is said to have made a balloon flight in India. I have not been able to verify any details. There are two rice paper prints of which one is hand coloured. It has on it the note "Mr. Fitzpatrick Kight's Ascension, bought in the native bazaar at Howrah, April 1853."

Perhaps, as a long shot, someone reading this may be able to fill in the details of the story and check the spelling of the gallant "Kight."

"Yes, yes; I am old. In me appears
The history of a hundred years."

Thomas Hardy.



This illustration is part of a poster advertising a Grand Fete, when Charles Green and his son went up in two balloons on Thursday 13th August 1835 to celebrate

HER MAJESTY'S BIRTH DAY

Some Aspects of High Performance Jet Aircraft

by

W. A. WATERTON G.M., A.F.C.
(Chief Test Pilot, Gloster Aircraft Co. Ltd.)

The 876th Lecture to be given before the Royal Aeronautical Society was held under the auspices of the Derby Branch on 12th March 1953. Mr. A. G. Elliott, C.B.E., F.R.Ae.S., Chairman of the Derby Branch, welcomed the visitors, especially the President of the Society, Mr. G. H. Dowty, F.R.Ae.S., Mr. N. E. Rowe, Member of Council and Chairman of the Branches Committee, and Dr. A. M. Ballantyne, T.D., A.F.R.Ae.S., Secretary of the Society. Mr. Elliott said that the membership of the Branch was now 247, of which 137 were main Society members, a high proportion. During the war the Branch had a total of more than 500 members; with the end of hostilities membership had decreased greatly, but it was building up again and he hoped that the number of ordinary Branch members would increase.

Mr. G. H. Dowty, President of the Society, taking the chair for the rest of the meeting, expressed his pleasure at presiding at the first Main Lecture of the Society to be held at Derby. The lecturer was an old friend of his and he knew his work, not only in the United Kingdom, but also on the other side of the Atlantic where a few months ago he had been testing the Avro Canada C.F.-100 fighter, which was now in production. A Canadian by birth, Squadron Leader Waterton had joined the R.A.F. with a short service commission in 1939 after service with a Canadian Cavalry Regiment. He served during the 1939-45 War with Fighter Squadrons, the North Atlantic Wing of Transport Command, Fighter Command Meteorological Flight, and as O.C. Flying, A.F.D.S., Central Fighter Establishment. In 1946 he joined the High Speed Flight, Tangmere, and later that year joined the Gloster Aircraft Company as test pilot. In July 1952 he had been awarded the George Medal for his successful landing of the prototype G.A.5 delta fighter (the Javelin) when in grave difficulties.

1. Introduction

Most sections of the Aircraft Industry with something to make, something to describe or something to sell will doubtless find much to take issue with in what is about to be said. No apologies are forthcoming, however, since it is proposed to speak about, and of, aircraft as found and experienced by pilots and operators.

Along with Lease-Lend the North American idea of high pressure salesmanship appears to have permeated British aeronautical matters together with all the superlatives ending in "ER." Of all mankind's ingenious devices probably none are more full of compromises than aeroplanes, therefore adjectives describing one or more of their aspects may be noteworthy but, when they tend to overflow, a sceptical eyebrow may well be raised.

Skilled slide rule operators and graph drawers, like legal experts, can equivocate and make plausible any aspect of a subject on which they choose to elucidate. The pilot, and particularly the test pilot, however, is in rather a different position. He may be fooled and he may be fobbed off but he is in no position to do likewise even if he were ill-advised enough to consider such a foolish course of action in the interests of his charge.

Be it about a complete aircraft, an engine, equipment or ancillaries no test pilot can long "Shoot a Line" with impunity. There are far too many of his own kind with healthy respects for their own well being only too ready and willing to prove him wrong for their own good, and rightly so.

Whereas aviation, a quarter of a century ago was in the immediate hands of enthusiastic builders, pilots and operators, the position has somewhat altered in recent years, to the extent that aeroplanes and their operation are first and foremost very large, and not unprofitable, commercial enterprises. Air crew are, therefore, at best necessary but perhaps undesirable adjuncts to the whole scheme of aviation. Since, however, they have the advantage of electronics in adaptability, flexibility, serviceability and, initially at least, easy production, piloted aircraft may yet be with us for a day or two. Herewith then, for consideration, are some observations and practical experiences on Some Aspects of High Performance Jet Aircraft.

2. Discrepancies between Published and Actual Performance

At one period of my flying in the R.A.F. I was privileged to be in a unit which made tactical and comparative trials of German, American, Italian and British aircraft, engines and articles of equipment. These were no theoretical trials corrected to a common basis by formulae and mathematical reduction, but an actual setting of aircraft against aircraft in combat conditions, bar the shooting. Apart from the disproving of the Press-sponsored popular conception that Me109 wings fell off under 2*g*, some extremely interesting facts became evident—some facts which did not coincide with published and measured figures of performance. Such factors may well apply even today with our present generation of aircraft and therefore, on past experience, here is an account of some of the observations made at that time.

Rate of climb was no indication of angle of climb of an aircraft. Spitfires and Hurricanes with 3,000 ft. and 2,500 ft. per minute rates of climb, frequently stalled and spun out trying to hold their sights on Ju88's of only 1,500 ft. per minute rate of climb. This was because

the best climbing speed of the Ju88 was lower and at an angle which put the fighters in trouble.

Level speeds between aircraft varied greatly with small increments of dive. Spitfires (367 m.p.h.) and Hurricanes (335 m.p.h.) in particular were hard pressed to catch Ju88's (295 m.p.h.) if the latter put its nose slightly down to reach sea level in the direction of "the Fatherland." For a slight degree of dive the Ju88 increased its speed out of all proportion to the British fighters for the same angle. If the angle of dive were, say, 20° or 30° or 45° instead of 5° or 10°, the fighter came into its own but then had to use full power for long periods in level flight, at the same time being at the disadvantage of having to climb up to attack the German. Many, indeed, were the British fighters which, by virtue of a low overtaking speed in this condition and limited fuel capacity, had to abandon chase before coming within the effective range of their armament.

Rates of turn and radius of turn, too, could be deceptive. The FW190 which couldn't "smell a Spitfire" in a prolonged turn would yet *initially out-turn* the Spitfire by virtue of its superb ailerons which enabled it to flip onto its side and into a turn rapidly, so changing its direction before the Spitfire, with its relatively inferior aileron control. In a prolonged turn, if the German were inexperienced enough to continue, the Spitfire came into its own. The German fighter, again by the grace of excellent and superior lateral control, could whip through 90° onto its back and into a dive, helped by its non-stuttering fuel injection engine or, could even reverse its turn through 180° so rapidly that British fighters could only report a flick (usually a fatal manoeuvre from a pursuing fighter which could easily bring its sights to bear if the pursued reversed its turn).

3. Control/Stability

The following examples are merely quoted to show that figures and theory do not always tell the whole story any more than do P.R.O.s (Public Relations Officers). It is hoped therefore that the following comments, based on experience, may be of interest in so far as they represent the views of the user. Since they cover a wide variety of subjects, this paper may become somewhat disjointed, for which due apology is made.

The most economic and efficient aeroplane is one which has sufficient performance, strength, control and equipment to do the job required of it, be it dropping a bomb, shooting down an enemy, delivering a load, taking photographs or training pilots. It therefore becomes a compromise of the various factors which go together to provide the correct combination. This is a most important concept and one which is often forgotten, too much stress being paid to the unimportant or to one particular aspect to the exclusion of others no less important.

The early Mustang I with Allison engine and the Spitfire 14 will always stand out in memory as two examples of opposites. The first, one of the most aerodynamically perfect fighters with beautiful controls and handling qualities, was yet unfit for serious fighter operations by virtue of its lack of performance and general "gutlessness" in the climb and at altitude. The Spitfire 14 on the other hand was a vile aeroplane from the handling point of view, yet it had performance in climb, in altitude, in turning and in acceleration and because of these points it was a successful fighter, although it threw a lot of responsibility for success on the pilot. Had it combined the stability and controls of the Mustang how much easier would have been the pilot's job. When the Mustang was given performance with the fitting of the Merlin engine what a superb fighter it became. We in Britain from the days of the Camel have thrown a lot on the pilot to get the best out of our aeroplanes and unfortunately, in so doing have made the job unnecessarily hard and severely handicapped all but the above average pilots. In the past if our aeroplanes have had performance we have tended to "make do" with handling characteristics. Unfortunately there is some evidence to suggest that this state of affairs may still be continuing.

In addition to performance, which is an absolute essential, stability and control under all conditions of flight are essential to the pilot carrying out his job—to this must be added psychological necessities of comfort, vision and security. With the enormous increases of speed and altitude, coupled with that often overlooked but most vital factor—rate of change of conditions—the problems have increased enormously.

The stretching out of the speed, Mach number and altitude ranges, have played such havoc with control hinge movements, stability and damping that old proven methods are no longer adequate and performance has once again outpaced ability to control it to the necessary degree of precision to get the best out of the aircraft. The difficulties encountered can be summed up as follows:—

I. STABILITY

(*i*) A deterioration of static and dynamic longitudinal stability occurs with:—

(*a*) Increasing altitude.

(*b*) Low air speed (A.S.I.) and high incidences near the stall (swept wings in particular show these tendencies).

(*c*) Greater variation of engine power.

(*d*) In the transonic and possibly supersonic range.

Conversely large increases in stability tend to occur with very high A.S.I.s.

(*ii*) Variations in stability may further result from:

(*a*) Aeroelastic distortion.

(*b*) Up float and down float of controls.

(*c*) Compressibility effects due to local breakdown of air flow or turbulent air conditions.

(*iii*) A 100 kilometre closed circuit record attempt in a Meteor Mk. 4 against better judgment in a 60 knot gale, provided a most convincing example of these effects. At the 510 to 520 knot speed at which the aircraft was flying, at low altitude in gusty conditions, complete reversals of stick forces, from heavy pull to heavy push, were encountered. At these speeds the aircraft was in the range where its centre of pressure was subject to rapid shifts for small changes in

speed. In the end, with a following wind the aircraft put its nose down and elevator effectiveness deteriorated markedly as though the aircraft were flying at around 0·85 True Mach number (T.M.N.) instead of near 0·8. It would appear that with the tail wind the aircraft, although itself only flying at about 0·8 T.M.N., was covering the ground at round about the 0·85 mark. Should the speed of the surrounding air suddenly drop, a sudden rise in aircraft Mach number could occur and in this case undoubtedly did. Oblique air flow resulting from air pockets or gusts can also give rise to changes in Mach number. It would be interesting to know how many high speed aircraft through this phenomenon have hit the ground through loss of control or have broken up through instability.

II. DAMPING

Allied with problems of stability are those of damping and most important they are, too, if the pilot is to achieve the steadiness of aim and flight path essential to accurate sighting, gunnery, bombing or photography.

Unfortunately with the low dynamic pressures prevailing at altitude, damping, like stability, falls off seriously and constitutes a real problem to the pilot not only in carrying out a specific task but in the great concentration required to maintain accurate straight and level flight.

III. CONTROL

Not only are the basic flight characteristics of high performance jet aircraft possessed of more variables, but likewise so is the behaviour of controls over the increased speed, Mach number and altitude ranges. These effects are listed below:—

(*i*) Rises of hinge moments, with A.S.I. ranges, of 7 to 1 or over and Mach number effects in the transonic and sonic regions.

(*ii*) Lack of self-centring coupled with poor and unequal responses over the speed, Mach number and altitude ranges, as well as the angular range of control movements, result in lack of sensitivity, crispness of feel and effectiveness at low speeds, and over-sensitivity at high A.S.I. with excessive stick forces.

(*iii*) Changes of hinge moment characteristics with Mach number, especially in the transonic range where local breakdowns occur and give rise to buffeting and to stick forces beyond the pilot's strength to control easily.

(*iv*) Lack of effectiveness at supersonic speeds results in poor control.

(*v*) Deterioration of damping at high A.S.I.s and Mach numbers gives rise to undulating flight and even flutter in many cases.

All these variables are tied up with those of the medium through which the aircraft travels and can be related to A.S.I., Mach number and altitude, or combinations of these three. So numerous are these that the demands of stability and control over the performance range of modern aircraft have become tremendous and for the moment at least the poor aerodynamicists, in conjunction with designers, have been able only to supply, at best, partial solutions towards the ideal which pilots would like and which would enable the aircraft to achieve its maximum efficiency.

Boosted and power controls now appear to be the order of the day in British aircraft some ten years at least after being fitted as standard equipment in the Lockheed P38 and at least seven years after the Lockheed F80 and Republic P84 were fitted with full power ailerons. Even the latest generation of high performance British fighter aircraft have been forced to full power after attempts to get by on spring tabs and moderate power boost. Further complications have been induced by severe flutter tendencies encountered on some new aircraft that one cannot but feel that there is something amiss basically in our assumptions. Stretch of circuits and float of controls have further added to the twin problems of stability and control. Despite its many complications and disadvantages full irreversible power on control surfaces appears to be the only practicable answer at present.

The great danger of brute force is that it can cloak a great deal of ignorance; but for the moment at least let us accept the brute force as a means to an end and put up with the ignorance. This should not, however, be taken as justification to sit back without further action on aerodynamic lines in search of perhaps cheaper and less complicated solutions. The finest and highest performance in the world is of no avail unless it can be placed easily, quickly, precisely and accurately in position to carry out its appointed job or role.

After all, the MIG.15 appears to be supersonic without the benefit of power controls and so was the Bell XS-1. All of which brings us to the problems of supersonic flight.

4. Supersonic Flight

Transonic and supersonic flight are very much in the news today being subjects which, as yet, are comparatively little understood or explored, a topic of which many misrepresentations and much speculation, not to forget quite a few claims, have been made. The general impression appears to be that the aircraft climbs up to altitude, goes into a dive and screams out quite happily to the accompaniment of a loud bang or bangs with everything being "quite in order" in between.

This is not quite so. In the first instance supersonic flight has been of a duration measurable in seconds during rapid dives from high altitudes at very steep angles, usually well exceeding 45° from the horizontal. There have been exceptions in the cases of chemically powered research aircraft but such flights have been at extreme altitudes and of very short duration by virtue of the thirst of the rocket motors. Because of the terrific rise in drag at high subsonic speeds it would appear to be a day or two yet before sustained, or even significant, increases in the duration of supersonic flight will be attained. The present engines, excellent though they be, still require help from Sir Isaac Newton to overcome

high transonic drag. The more powerful engines undoubtedly on the way will help, but any rise in thrust immediately foreseeable is hardly likely to approach that "urge" gained from the earth's attraction when the weight of a medium aircraft is added to the engine power by putting the nose down—well down—into a dive.

Amelioration and lessening of dive angle, however, can be expected with more powerful engines, particularly if coupled with cleaner, sleeker aerodynamic shapes. By cramming multiple engines in small, heavily laden airframes of limited fuel capacity, we may well achieve level supersonic flight by accepting high landing speeds, lack of manoeuvrability, except at top speed, and very short range and endurance.

Together with the great increase in drag, transonic and supersonic flight, are posed further problems by our twins, stability and control, both of which manifest themselves somewhat in the supersonic and more particularly in the transonic range.

Experience so far with a variety of fighter aircraft of varying weight and aerodynamic form has confirmed the following general pattern of behaviour:—

I. IN THE TRANSONIC RANGE

(*i*) Changes in longitudinal stability which may take the form of:—
  (*a*) nose up changes of trim,
  (*b*) nose down changes of trim,
  (*c*) porpoising and longitudinal pitching.

(*ii*) Changes of lateral stability:—
  (*a*) alternate wing dropping through 10° to 20° or more,
  (*b*) a single wing dropping severely.

(*iii*) Changes in directional stability:—
  (*a*) directional oscillations with poor or no damping (snaking),
  (*b*) a sudden directional jerking or kicking over of the rudder.

(*iv*) Severe buffeting:—
  (*a*) of some main part of the structure,
  (*b*) of a control itself.

(*v*) A loss of control effectiveness:—
  (*a*) continued movement of a control produces no effect and may give the impression of a reversal since the aircraft may continue to deviate (*e.g.* stick farther back, nose continuing to drop is a common experience).

II. IN THE SONIC AND SUPERSONIC RANGE THE FOLLOWING ARE NOTED:—

(*i*) Cessation of buffeting and a smoothing out of the flight.

(*ii*) Stability becoming more normal.

(*iii*) Controls becoming more normal in so far as they centralise and do produce normal effects.

(*iv*) Heavying of controls with a great loss of effectiveness manifesting itself in very low rates of roll and a lack of elevator power. So deficient has been this latter control that recovery from the dive is invariably made on the trimming tailplane, or after a return to subsonic speed and elevator effectiveness.

III. SUMMARY

(*i*) Trailing edge controls do not appear to be the answer to either transonic or supersonic flight conditions, deteriorating to such an extent that control of the aeroplane is insufficient to manoeuvre it with requisite precision or rapidity. There is, however, a certain amount of evidence that trailing edge thickness can be of influence under these conditions but such research or theories have not, as yet, provided practical answers. Dive recovery on British and American aircraft has been on the moving tailplane—one aircraft has even resorted to locking its elevators to the tailplane and flying solely on trim in order to relieve buffeting and so achieve and recover from supersonic flight. It is no accident that the F.86 has gone to the so-called "flying tailplane" where the pilot's stick moves the tailplane as well as the elevators, nor is it remarkable that this is the aeroplane over which it is considered the pilot has control during such conditions, to the point of being really practical.

(*ii*) Heaviness of controls—buffeting and variation of hinge moments can adversely affect transonic and supersonic flight to the extent of preventing the latter. In these cases high power boost ratios or, more preferably, irreversible power controls provide an answer in giving the pilot sufficient power to correct manually control and stability upsets, such as wing dropping—aileron buffeting and porpoising.

(*iii*) The worst region appears to be around 0·93 to 0·96 or 0·97 True Mach Number (T.M.N.) and, if control can be maintained over this range, supersonic flight is usually easily possible. Provided that sufficient control could be applied, there appears to be no real reason why, if dropped from an "almighty altitude, even a brick shouldn't be supersonic."

(*iv*) It is surprising the effects small changes have on transonic flight conditions and how a small aerodynamic clean-up or modification can make an otherwise uncontrollable and dangerous aircraft capable of transonic and supersonic flight when previously it ran outside its pilot's capabilities or sensibilities in the 0·85 to 0·95 region.

5. Design and Manufacturing Tolerances

Designers and aerodynamicists have publicly deplored the lack of full scale information in respect of new aircraft and, to be sure, aircraft do not in all cases parallel their model tests in wind tunnels. This is usually put down to *scale effect*, a theory which can not be relied upon to account for all that happens.

Although tunnel models are made of some hard, dense, smoothly polished wood, such as mahogany, their full scale counterparts come into being with seams, orifices and "an epidermis" which is often varying in its profile due to manufacturing techniques and tolerances, as well as distortion in flight due to panting and "oilcanning." It is therefore no wonder that results do not agree.

Both in design and manufacture small irregularities are often accepted as either a normal condition unworthy of either further detail design and refinement, or else beyond easy manufacturing capabilities. It is submitted that small leaks, surface irregularities and lack of cleanliness in detail can cause detrimental effects in handling and impose performance limitations out of all proportion to their size. In support of these remarks the following examples of first-hand experience are offered.

(*i*) A large twin-engined heavy fighter having droop snoots fitted to the leading edges of its wing to flatten out the sharp peak in the lift curve at stalling incidence, predicted from tunnel results, failed to show this expected characteristic but gave up to 30 knots progressive stall warning through increasing lateral instability and buffeting. By cleaning up nacelle/wing root fillets and taping over the inboard and outboard (2 ft. from nacelle and tip) vertical 1/16 in. slots in the leading edge of the wing between the structure proper and the droop snoots, all lateral instability and buffeting disappeared completely, the aircraft showing a very sudden stall and sharp wing drop at the same original ultimate stalling speed, but minus the warning. The requisite 8 to 12 knots stall warning was then easily adjusted by the fitment of small spoilers at the wing roots. When the aeroplane was made to resemble more closely the tunnel model, it did in fact approximate its tunnel results, having initially shown vastly different characteristics.

It is of interest to note that this improvement also allowed an approximate 0·03 increase in Mach number and that further small refinement, plus increasing control boost ratios to enable the pilot to hold a wing up, endowed the aircraft with supersonic capabilities which have, in fact, been realised.

On the same aircraft, wing tip tanks resulted in a considerable drop in aileron effectiveness. Tufting and photography showed a breakdown over the outboard one-third of the aileron which was put right by a small change in fairing between tank and wing.

(*ii*) A well-known aircraft at over 430 knots A.S.I. suddenly changed its rudder trim and in certain cases started appreciable directional snaking. Pilots' observations showed engine intake lips and nacelle intake skin to be sucking in, coincident with this phenomenon. A few pressure venting holes in the right places resulted in a cure for this particular skin deformation.

(*iii*) On Meteor 7s a deterioration in directional characteristics can result from a loose or badly fitting canopy sealing strip along the starboard hinge line.

(*iv*) A fighter aircraft which exhibited heavy stick forces and uncontrollable aileron buffeting and reversals in the lower 0·9 Mach number range was improved by a small local clean up in front of one aileron, to the extent that the pilot could control the aeroplane relatively easily laterally in the transonic range and achieve supersonic speed, which previously could not be reached.

(*v*) A new canopy fitted to an old established aircraft gave rise to noticeable vibration of rudder and elevators, as well as considerable cockpit noise and discomfort. Despite the protests that a gap between canopy valance and fuselage could not be bettered in production, it was sealed with felt strips experimentally with the result that cockpit noise and discomfort almost entirely disappeared and so did all the elevator and rudder vibration.

(*vi*) An accurate and constant adjustment to control surface shrouds of a small fraction of an inch made quite decent controls out of those previously showing extremely adverse characteristics.

(*vii*) Stalling characteristics of certain aircraft have varied from good to vile with changes in filler and painting of leading edges of mainplanes; so have Mach number characteristics. One well-known aircraft has had its stalling characteristics put right and was made acceptable by the application of filler on the mainplane and leading edge forward of the ailerons.

(*viii*) Jet aircraft have been found to have dropped as much as 80 knots from their original top speed from "bashed cowlings" and leading edges resulting from careless handling and maintenance by clumsy ground crews.

Countless other examples of the effects on handling and performance caused by small irregularities and lack of attention to detail design, manufacturing technique and tolerances, as well as careless maintenance, could be quoted but it is hoped that the foregoing may show how important such items are. Unfortunately, there is some evidence that the British Industry in general may not take seriously enough the fact that small details can have such adverse effects out of all proportion to their size.

If a study is made of photographs of many aircraft, visual evidence is often to be had of wrinkling and panting of skins—a most pertinent factor in good control and even stability.

From the foregoing one wonders whether or not due and sufficient thought has been given to the radical alteration of methods of design and construction, which basically have changed but little in the past 15 years. Would not heavier skins and less light internal "tinmongery" provide more accurate surfaces, without panting and distortion due to air loads or suctions, as well as conferring greater stiffness as a deterrent to aeroelastic distortion? At the same time would they not provide a firm foundation for power control jacks to push against and additionally, allow more internal space for fuel and equipment, particularly inside wings?

6. Performance/Aircraft Configurations

Some remarks are now made on current topics of controversy.

There has been much talk of the superiority of the swept wing over the straight wing, the delta wing over the lot and even later still, the straight wing coming into its own again. To say that one is better than the other without qualifications is deceptive, to say the least. Although one hears at great length the virtue of one configuration or another, the defects of that particular layout are no more mentioned than are the advantages of the rival. It must be patently clear that each has something to offer and each has certain disadvantages and only that configuration offering the best possible combination for the role of the aircraft can truly be said to be most advantageous.

Determining factors in a layout must be:

(*i*) Generation of lift through the speed and Mach number range.

(*ii*) Good stability characteristics.

(*iii*) Low drag characteristics over the speed range.

(*iv*) The ability to be made sufficiently strong and sufficiently light.

(*v*) The provision of adequate space for the demands of equipment services and fuel, as well as future requirements for a reasonable period ahead.

TURNING CIRCLES/ALTITUDE PERFORMANCE

1. *Power Loading*

(*i*) One very prevalent school of thought maintains that given sufficient power, wing loading becomes relatively immaterial, a highly powered, heavy aircraft being able to hold its own with a more lightly loaded adversary. Given equal lift coefficient characteristics this is not so, since for a given A.S.I. the more lightly laden aircraft will be capable of attaining more g or, conversely, can achieve a given g at a lower speed and so out-turn the machine with the heavier wing loading. There is an optimum power required to overcome increased drag and here again the more lightly loaded wing with its reduced incidence bestows an advantage.

(*ii*) Superiority in tightness of turns was claimed of the swept plank wing over the straight wing and this was partially true in so far as it showed superior lift characteristics at high Mach numbers, whereas those of the straight wing were falling off. In most cases, however, for structural reasons, this advantage was largely thrown away by the higher wing loadings employed by swept wing aircraft, since at lower speeds and Mach numbers the lightly loaded straight wing generated lift which the other could do only at higher forward speeds. Thus could a straight winged aeroplane possess better turning capabilities and thus is shown up the benefit of a light wing loading.

2. *Wing Loading*

This must always be a factor in turning and climbing capabilities, particularly at high altitudes.

(*i*) Generation of lift at a given speed will always provide an indication of turning capabilities and the aircraft which can achieve, say, a $3g$ turn at 0·8 I.M.N. will handily out-turn one which must do a 0·9 I.M.N. to achieve a similar value of g.

(*ii*) Provided that lift coefficient does not fall off with Mach number and sufficient power is available to overcome drag, the low wing loading should show up favourably every time.

(*iii*) If a low wing loading can be coupled with adequate power loading, plus sufficient strength, it not only scores in this important regard but provides the following in addition:—

(*a*) A lower stalling speed.

(*b*) A higher ceiling.

(*c*) A useful low speed range for advantageous search and handling qualities under instrument, night and bad weather conditions.

(*d*) Lower approach, landing and take-off speeds, allowing the use of smaller aerodromes or a bigger factor of safety on present ones.

(*e*) A greater range of usable and controllable speed, particularly at altitude where, with roughly all modern aircraft showing compressibility manifestations at 0·93 to 0·96 T.M.N., the lowering of the stalling speed by 20 to 30 knots gives the pilot comfortable flying, control and manoeuvrability at speeds at which a more heavily laden aircraft is on a "knife edge," or falling out of the sky.

3. *Aspect Ratio and Span Loading*

The advantages of high aspect ratio and low span loading have long been recognised as factors determining low induced drag and aerodynamic efficiency, making for excellent altitude performance. Perhaps no better example of these features can be found than in sailplanes, yet such a form could not be incorporated in military or high performance aircraft to operate over the requisite speed, Mach number and altitude ranges by virtue of structural requirements.

Low aspect ratio and high span loadings, it is true, do militate against getting the best out of an aircraft, but much can be recovered by keeping wing loadings low and so keeping down incidence, particularly at altitude.

4. *Plan Forms*

Any aircraft being a compromise it is interesting to see what each has to offer:—

I. The straight plank wing provides good control, stability and structural possibilities, possibly because so much research has been devoted to it and so much experience has been gained over many years. In addition, if made thin enough it can offer good transonic and supersonic possibilities, but only at the expense of loss of space and severe structural problems and an increase in wing loading.

II. The swept plank wing can offer a notable improvement over the straight wing of equal thickness in drag reduction at high speed and Mach numbers and in lift coefficient at high Mach number. It can provide

reasonably good transonic and supersonic capabilities. It suffers, however, from structural problems, particularly in torsional stiffness in weight and in space, and in stability, both longitudinal and lateral.

III. The crescent wing is an effort to combine the root characteristics of the delta and the outer wing features of the straight or slightly swept plank wing. Theoretically this is admirable, from aspects of stability and control, but it is difficult to see how it can possess the space and structural advantages of the pure delta since it has neither the chord of the latter nor the average thickness chord ratio. In achieving a better span loading it needs to be of greater span or less chord than the pure delta and so loses further structural advantage, save by resorting to less area and so going to a higher wing loading, which may well negate its advantages.

IV. The delta plan form does appear to provide an extremely reasonable and promising compromise in offering many features in which these previously mentioned forms are lacking:—

(*i*) Excellent Mach number characteristics as to change of longitudinal trim and rise of drag due to Mach number.

(*ii*) Low high-speed drag.

(*iii*) A compact form of sufficient strength to cover high indicated air speeds.

(*iv*) An internal volume providing space for the masses of ancillaries and equipment with which modern aircraft are burdened, not to forget the not inconsiderable libations required to keep powerful engines happy for reasonable periods.

(*v*) The ability to cope with future requirements in the line of developments in more equipment, more powerful engines, more fuel and more performance, without major redesign.

(*vi*) It has been said that the delta suffers by virtue of its low aspect ratio and high span loading. This may well be so, were high wing loadings the order of the day, but it is my conviction that the low wing loadings of our British deltas more than make up any losses due to adverse span loading conditions. It has been my personal experience that the low speed handling and general qualities of an aircraft are a measure of its high altitude performance. On this theme I have further noted that behaviour near the static and dynamic stalls is a faithful indication of characteristics under conditions of compressibility.

(*vii*) Provided that the crescent shapes keep their wing loadings down to near those of the deltas they might prove formidable contenders for the honours of the "best," although possibly at serious disadvantages as regards compactness and stiffness which might well impose low altitude speed limitations, internal storage capacity and doubtless loss of drag efficiency by virtue of large separate bodies and empennages, which brings up the question of tails on deltas—"to have or to have not."

(*viii*) There is much to be said for dispensing with horizontal tail surfaces with consequent reduction in drag, saving in weight and mechanical complexity, for perhaps certain losses at the extreme end of the speed and Mach number range. It was felt in the case of the Javelin that the design must be exploited to the full at both ends of the performance range and so, on the basis of existing knowledge, flaps were provided and a separate high mounted tail unit to provide stability at both low speeds and very high speeds and Mach numbers. This policy certainly appears to have paid dividends so far.

(*ix*) The Vulcan, on the other hand, is undoubtedly the soundest conception for its role which, in all likelihood, is not to such severe requirements for high speeds and Mach numbers and manoeuvrability as the fighter, but must achieve the best possible weight/load ratio coupled with the most advantageous high speed drag coefficients. A further point here is that fighters may be expected to have a power/weight ratio of about 0·5, whereas that of a laden bomber is not likely to be more than of the order of 0·3. As to the landing case it is to be remembered that a fighter normally comes in at about 70 to 75 per cent. of its all-up weight, whereas the bomber normally lands at about 50 to 60 per cent, of its laden weight. Thus, each would appear to be the best solution within the limitations of the specification to cover the intended role of each.

(*x*) Performance-wise, the deltas have certainly not been lacking, while handling qualities have been surprisingly "ordinary." Practical experience with deltas has shown that they are normal aeroplanes and that they are practical, easily handled aircraft without, so far, any revealed deficiencies peculiar to themselves. Problems there are and have been, but only those of the same nature and magnitude experienced with modern, high performance aircraft of more orthodox shape. Changes and modifications may perhaps be expected as time goes on, but, most important of all, the delta is a relatively new aeroplane, yet as such it is already more than holding its own with designs which represent years and years of step-by-step progress. Surely no greater recommendation for the formula can exist than this and what a fortuitous augury for the future of the species it portends.

7. The "Vision Barrier"

The "vision barrier" is a catch phrase of extreme current value for publicity purposes, but in reality high altitudes of 40,000 ft. and upwards do present problems of vision and sight not generally appreciated by laymen. These must be of increasing awareness to pilots, staff and planning personnel, since they cannot but have effects of considerable import on all concerned. These may be summarised as follows:—

I. GLARE AND ULTRA-VIOLET LIGHT:—

(*i*) The lack of dust particles, water vapour and haze, which are generally encountered low down, results in sunlight of extreme brilliance and of considerable embarrassment in its effects on the human eyes. Filters, goggles and visors can moderate these effects to some extent, but they are prone to misting, make reading of instruments more difficult and, in general, are not completely satisfactory.

(*ii*) Severe sunburn can result from prolonged exposure at high altitudes.

II. LACK OF CONTRAST:—

Lack of proximity to cloud masses with high or distant cloud taking on a greyish hue as the sea or earth usually does, results in a rather limited colour scheme, the only relief being the blue sky. A camouflaged aircraft blends into this indefiniteness and so is extremely difficult to pick up among its surroundings.

III. LACK OF REFERENCE POINTS:—

The fact that there is so much space with no horizontal or vertical features of prominence such as cities, shorelines, mountains, hills or rivers, or even cloud masses, makes the picking up of targets extremely difficult. In one's own experience, if one tries to search out an aircraft in an expanse of sky, or a swimmer in the sea, knowing only the general direction, one knows how difficult detection can be.

IV. FOCUSING:—

Another problem facing aircraft crews is the necessity of not only searching and straining their eyes in space to extreme range, but also the necessity of being able to see and operate the instruments and equipment within the cockpit, and only a few inches from the eyes. Shifting from one to another means a constant disruption to the focusing of the eyes. Designers and manufacturers may well take note of the aid which can be given crews by making instruments quickly and easily readable, or better still, ensuring engine and aircraft control which does not require reference except at very occasional intervals.

V. SIGHTING TIMES:—

High relative speeds, except in the case of stern chases, mean that the time other aircraft may be in sight is very short indeed since the range of human vision at high altitudes is not likely to be more than about five to eight miles, considering the size of aeroplanes. This means that another aircraft, on a 90° crossing path will be in the pilot's range of vision not over a minute. A machine approaching head-on will only be picked up a matter of 15 seconds or less before being opposite another.

VI. REDUCED VISION DUE TO BLIND AREAS:—

Air to ground vision with even the excellent view generally provided in jet aircraft is much reduced at altitude, increased height resulting in increased blind areas in respect to the ground. As an illustration: in an aeroplane with good side and forward vision of 12½° over its nose, in level flight at 40,000 ft. the pilot cannot see anything under about 35 miles away, rising to about 60 miles at 5° incidence. To either side he is not likely to see anything closer than about 20 miles and so, without resorting to manoeuvring, is blind to at least some 1,600 square miles below him and more at greater heights.

VII. DEVIATION FROM FLIGHT PATH:—

Although not strictly in the same category as the foregoing paragraphs, it is interesting to note that at low altitudes at even 600 m.p.h. a landmark which can be discerned five miles away must be identified in the 30 seconds before it recedes behind the aeroplane. Also in climb/descent or direction, 1° deviation from course results in 1,000 ft./min. rate of climb or descent, or 5° off course causes an aircraft to be roughly a mile off track for every minute. The difficulties of navigation and target detection, especially in conditions of poor or bad visibility, are therefore clearly apparent.

8. Economics of Modern Aircraft

Of ever increasing importance in these days is the increasing complexity and cost of modern aircraft. One can remember the days when it was predicted that the jet engine was going to bring with it a new era in simplicity and economy of manufacture and operation. Unfortunately this has not been the case with either the engine, the airframe or its equipment, all of which have grown with the demands of increased performance and operational requirements.

In its infancy the jet aircraft was looked upon, and indeed suggested, as a very much simplified aircraft, both from the aspect of its airframe and engine.

THE AIRFRAME

Smaller undercarriages much reduced in weight by the introduction of shorter legs and lower ground clearance, made possible by elimination of propellers, were promised. This may have been true of the E1/44, Vampire and possibly the Meteor, but it is certainly not true of our latest aircraft with higher mounted wings. Anyone doubting this statement would do well to look at one or both of our latest day fighters parked alongside an F.86.

HYDRAULICS

Hydraulics have, if anything, increased with the addition of air brakes and the increased operating requirements of the main services. The necessity for boosted and power controls, and the general increase in operating pressures, have increased weight and complexity. There is evidence, however, that further hydraulic complexity and equipment is essential, for flying controls in particular.

ELECTRICS

Electrical requirements have gone up markedly with the adoption of electric canopy operation, electric trimming of control tabs and particularly tailplanes; added radio, radar and *g* equipment, new sighting and fire control equipment, as well as possible provision for more complex bombing and rocketry. Furthermore, the adoption of electrically-controlled main services,

auto-stabilisers and instruments, blind flying aids and apparatus, plus navigational aids, have all added to the overall complexity and weight.

(*i*) While electrics are no doubt a very pleasant and desirable way of accomplishing the many tasks around an aeroplane, manufacture and maintenance require specialist personnel in large numbers, as well as considerable test equipment and facilities.

(*ii*) There are many problems of corrosion, brush wear at altitude, heating, pressurisation of certain equipment, cooling and shock mounting, yet to be solved.

(*iii*) Of all equipment on aircraft, as in motor cars, electrics are probably the greatest source of failure and for that reason not at all popular with pilots. Electrical failure is usually complete, and rarely partial, as in the cases of hydraulics. Furthermore, damage can have rather serious secondary effects, such as fire.

INSTRUMENTS

As with other requirements, instruments have grown in number, not only to deal with the added equipment, but to enable close control of the engine which, unfortunately, has not lived up to its advance notices of simplicity. No effort to reduce size or weight, as in America or Czechoslovakia, has been apparent in the United Kingdom, usually on the score of accuracy, yet our more recently introduced instruments appear to be worse in this respect than their predecessors. Scales could be reduced advantageously in many cases to show only a small portion of the cruising range with the accent on the range of limitations, plus a danger range. Reduction in size is most pertinent, since great accuracy is of no virtue when of necessity it is negated by parallax through positioning, or positioning well outside the easy range of the pilot's vision.

This may well be the time to speak up on warnings —one school of thought has decreed that warning lights and emergencies should be with the appropriate control requiring action. This is all very commendable, and would be so if such controls were on top of the instrument panel, but this is not the case and the warning as such is almost valueless since it is rarely seen when it first appears. Since the purpose of a warning is either to let the pilot know emergency action is required, or in some cases preventive action, the important thing would seem to be that the pilot received indications at the earliest possible moment. This dictates that the indications be in his line of V.F.R. or I.F.R. vision (*i.e.* on the combing or on the top of the instrument panel) and it is suggested that they should all be grouped in one spot, preferably a small panel, say, 4 in. x 4 in. or 2 in. x 6 in. They might also be of two distinct types, say, yellow and red, plainly marked in an easily learned logical order (*e.g.* engine fuel system warnings on the same side as fuel indicators or controls), the first to indicate a patently dangerous but not necessarily a panic warning (*i.e.* low fuel pressure or high bearing temperatures), which by an alteration of power the pilot could prevent damage and subsequent failure. The red warning would indicate a dangerous condition such as fire, requiring immediate action or evacuation of the aircraft. The pilot therefore, is warned at the earliest possible instance, is made to think and sort out his action before doing anything premature—and the danger of missing the warning is eliminated.

A saving in space would result and as a further development, why should not a series of three types of lights be used (green, amber, red) to replace engine, fuel pressure, oil pressure, hydraulics and perhaps certain temperature and electrical indications.

ENGINES

The comparatively simple jet engine has never been notoriously cheap even in its original centrifugal form which, at least, had the virtue of relatively few moving parts but yet required expensive, often difficult to work, metals and alloys to be manufactured within extremely close tolerances and to be fitted, adjusted, assembled and balanced to very fine limits. Any relaxation in these matters spelt short life and inferior performances. Had we been content with moderate thrusts, the advertised blessings of simplicity and long life might well have materialised, but the uprating of engines, together with their characteristics of control, especially at altitude, have caused more failures and lower overhaul periods than were anticipated. As this has been so with centrifugal engines, so to a much greater degree has it been with the axial flow engines with their 6-7,000 compressor blades and multi-stage turbines.

STANDARDISATION

A period spent in the Aircraft Industry of North America was a revelation as to the vast amount and variety of "off the shelf materials," components, ancillaries and equipment available to designers and fabricators. Another "eye opener" was the aggressive competition of the manufacturers of these articles in producing more attractive products as to size, weight, reliability, cheapness, air crew utility and appeal—a feature conspicuously absent in British firms which, in all fairness, may be too rigidly bound by official requirements to exercise much initiative on their own.

It would be interesting to know the number of stock components on two roughly similar American aircraft, compared with two British aircraft of a similar specification. Certainly in the case of the latter virtually everything about a new aircraft is prototype. This may be an excellent thing in maintaining design staffs, testing sections and experimental shops, but it cannot but play havoc with the Air Estimates. I know "maximum efficiency" will always be quoted but is it not a worthy challenge to the ingenuity of the designers to build their various aircraft configurations around fewer, more standardised, ranges of components and equipment? Surely one type of undercarriage or tailplane actuator, to quote but two examples, could be made to do for virtually all aircraft built to a similar specification as to weight and performance? Surely this must be one of the solutions to the cheap fighter or for that matter, cheaper aeroplanes of all types.

9. Summary of General Experience

1. PRECIPITATION / ICING / FREEZING

Low Altitude	*High Altitude*
(*i*) Damage to finishes.	The first two are not really relevant, but the third, "freezing," is.
(*ii*) Damage to aerials after causing failure, with resulting airframe damage.	
(*iii*) Damage to dielectrics, particularly freezing of controls.	Freezing of trimmers, throttles, fuel cocks, cocks, etc., demands freedom from moisture and meticulous care in correct lubrication.
(*iv*) Damage to engines and loss of performance from icing.	
(*v*) Denser charges into engines resulting in water injection through cloud flying making for reduced fuel consumption or better speeds.	

2. OBSTACLES / BIRDS / INDUSTRIAL HAZE / MURK / INSECTS

Low Altitude	*High Altitude*
(*i*) Severe structural damage can result from hitting birds at speed.	Not relevant.
(*ii*) Loss of engine performance can result from dirt and carbon deposits as a result of "smog" on axial compressor blades, and on turbines.	
(*iii*) Insects and dirt on laminar flow surfaces can cause a breakdown of air flow, resulting in altered stalling performance and loss of performance.	

3. ALTITUDE

Low	*High*
Sea level to 10,000 ft.	40,000 ft. to 50,000 ft.
High density	*Low density*
Temperature 15°.	40,000 ft.: pressure 18 per cent. sea level; density, 25 per cent. 50,000 ft.: pressure, 11 per cent. sea level; density, 15 per cent.
High mass flow.	Low mass flow.
Aerodynamic loadings high.	Aerodynamic loadings low.
Structures highly stressed.	Structures lightly stressed.
High stability.	Low stability — margins low. Rapid shift of centre of pressure near critical Mach No.
Damping good.	Damping poor — high shock and inertia loads.
Drag high.	Drag low—Meteor 30 per cent. at 40,000 ft.

Low Altitude	*High Altitude*
High engine thrusts.	Low engine thrusts—reduced by 60-65 per cent., but not to the same extent as actual drag.

Gravity effects similar at both heights, but due to reduced drag correspondingly more effective for a given angle of dive.

The foregoing are manifested to the pilot by the following:—

Low Altitude	*High Altitude*
Noise.	Lack of noise.
Pilot capable of breaking aircraft under *g* loads before it stalls.	Aircraft stalls at low *g* values.
Heavy control forces.	Light control forces except under conditions of Mach number disturbance.
Easy and positive trimming.	Trimming difficult and not accurate.
Controls effective and positive.	Controls sloppy and often relatively ineffective.
Acceleration into compressibility is approached relatively slowly with plenty of warning over a large range of indicated air speed (I.A.S.).	Acceleration due to gravity effects is rapid, the aircraft easily showing compressibility effects for slight dive angles and relatively low changes in I.A.S.
High I.A.S.—medium Mach number.	Low I.A.S.—high true air speed (T.A.S.) (at 40,000 ft.). Half of I.A.S. at sea level for the same T.A.S. High Mach numbers.
A broad speed range from the stall to cruising speeds and to compressibility speeds of in the order of one to 6 or 7 for late types of fighters.	A much restricted speed range from stall to cruising and compressibility speeds of in the order of one to about 2·5.
(Meteor 350 and 425 I.A.S.).	(Meteor 120 and 140 I.A.S.).
An appreciable range of I.A.S. between cruising and compressibility speeds.	A shortened range of I.A.S. between cruising and compressibility speeds.
(Meteor 75 knots I.A.S.).	(Meteor 20 knots I.A.S.).
Relatively low incidence for a given T.A.S.	Higher incidence for the same T.A.S.—the aircraft flying closer to its stalling incidence at all times—hence less *g* can be generated in turns.
The pilot can relax knowing he has plenty in hand under pretty well all conditions of flight. The aeroplane is stable, trims easily, will not easily approach compressibility near the stall and can he handled roughly.	At altitude the aircraft is never far from trouble at either end of its speed range—it is apt to be critical, requiring careful, gentle handling and considerable concentration.

4. TEMPERATURES

Low Altitude	*High Altitude*
High—may be up to 35°C.	Low—57°C. to 70°C.
High speed of sound, 762 m.p.h.	Low speed of sound, 660 m.p.h.
Higher speed for same Mach number.	Lower speed for equal Mach number.
Temperature rises through friction (40°C. at 600 m.p.h.).	Cracking of glass and Perspex through rapid contraction.
Loss of engine thrust resulting in longer take-offs, poor climbs and reductions of speed up to 40 knots.	Differential contraction/expansion causing loss of tension. Slop and play in controls.
Loss of strength of Perspex causing failures, heating of aircraft skin, over-heating of cockpit and cabin.	
In some parts of the world, *e.g.* Canada, Siberia, low temperatures at sea level give rise to early compressibility effects but at high I.A.S.	

The effects of temperature on aircraft are largely due to the high rate of change of temperature brought about by more rapid climbs and descents. As an example, an aeroplane parked in the sun or in a warm hangar may, in a very few minutes, be at high altitude—a 40 ft. fuselage cooling rapidly may contract as much as 2·5 inches and much of this contraction may take place before the cold has a chance to soak through to the more protected innards, such as control circuits.

5. HUMIDITY

Low Altitude	*High Altitude*
Usually high—especially in the U.K.—causing corrosion.	Low—causing crew discomfort and electrical troubles such as icing and high generator brush wear.

Humidity effects are largely the result of rapid change of conditions, a damp aircraft climbing rapidly to altitude collects frost which is helped out by the respiration of the crew. On descent the cooled aircraft collects moisture and ice from cloud and damp air resulting in icing and misting of structure, windscreens and canopies which reduce or blank out vision on the approach and landing and increase the risk of collisions. At height the possibility of electrical and generator failure appears to be greater.

6. TURBULENCE

Low Altitude	*High Altitude*
May be high.	Clear air turbulence is frequently experienced at even over 40,000 ft. in the U.K. and, especially, in the tropics. It is not likely to break up an aircraft through excessive *g*, but can cause large stability upsets in a region where stability tends to be reduced, damping is
In cumulo nimbus turbulence may break up aircraft through high and/or reversals, of *g* loading.	
Local Mach number changes may result.	
Heavy control forces get through to the pilot.	
Instrument flying is difficult; it becomes prudent to reduce speed not only for crew and passenger comfort but also to prevent overstressing the aircraft.	relatively poor and controls less effective. For these reasons it can be unpleasant, especially on instruments.
Down-draughts can put aircraft into mountains and can foul landings.	

7. VISIBILITY/RECOGNITION/NAVIGATION

Low Altitude	*High Altitude*
Vision good—2½° over nose and moderately high cockpit combings results in extremely good vision.	The same view at altitude means the nose angle subtends 35 miles at 40,000 ft. in level flight or 60 miles at 5° incidence.
	Nothing can be seen for 20 miles to either side of the aircraft, thus the pilot is blind to at least 1,600 sq. miles in front, to the side and below. Difficult to locate another aircraft in space due to glare, lack of contrast and lack of reference point.
At 600 m.p.h.—a landmark visible five miles away is in front of the pilot for 30 seconds.	
At 600 m.p.h.—1° = 1,000 ft. per minute displacement.	
5° off course means approximately one mile per minute off track. This also applies in elevation as well as azimuth.	

8. MANOEUVRABILITY/SIGHTING/GUNNERY

Low Altitude	*High Altitude*
Generally good.	Turning circles large—*g* values low. Formation difficult—sighting and gunnery difficult. Military problem more severe than civil.

9. PSYCHOLOGICAL

Low Altitude	*High Altitude*
Oxygen satisfactory up to 37,000 ft.	Oxygen satisfactory up to 37,000 ft.; pressurisation desirable, essential over 43,000 ft.
	With pure oxygen but no pressurisation life expectancy drops from one to two minutes at 45,000 ft. to 15-20 seconds at 50,000 ft. Pressure breathing will get one down to a safe height from 50,000 ft., but over that altitude full pressure suits are essential.

10. Concluding Remarks

1. The pilot, with all his faults and deficiencies, has a difficult job to do, especially under conditions of military or naval combat operations or at any time under adverse weather conditions and, until he can be dispensed with, anything which will facilitate his control and handling of the aircraft will result in greater safety, as well as operational or commercial efficiency.
2. In military aircraft performance by itself is no guarantee of success—it is essential, but can only be realised operationally if the stability and control of the aircraft is such that it can be handily and precisely positioned with the speed and steadiness essential to bring its sights, guns or rockets to bear on its adversary, to aim and drop its bombs with accuracy or to take its photographs from a steady platform. Additionally, it must be easy to fly at extreme altitude, over its speed and Mach number range and on instruments.
3. Transonic and supersonic flight pose many new and virtually unexplored problems. However, aerodynamic cleanness over-all and in detail, coupled with powerful controls and the power to move them easily and the adoption of "flying tailplanes" provide the keys with which to unlock the doors to further progress and exploration.
4. Aerodynamic cleanness insofar as small details are concerned is not generally appreciated as being of great importance, yet lack of it has proved in fact to have far reaching effects on stall, high speed and compressibility behaviour.
5. A revision of structures is overdue in the U.K. towards eliminating the present masses of light internal fittings; the room thus saved could be used with advantage in virtually every case to house more fuel.
6. As to strength, space, accessibility, stiffness and compactness, coupled with high performance potentialities, the delta plan form has much to commend it and is living up to the high hopes held out for it.
7. Problems of vision at high altitudes are real and the case is strong indeed for the fighter equipped with search and gun-laying radar.
8. A greater standardisation of components large and small should be a challenge to design staffs. This is the only real way ahead to cheap aircraft. Simplification of present instruments, detectors and warnings, with better control of engines are highly desirable.
9. As the characteristics of the medium through which aircraft fly changes in pressure, in density, in humidity, in temperature and in flow characteristics, so does the character of the aircraft itself.

Discussion

SQUADRON LEADER H. N. D. BAILEY (Assistant Chief Test Pilot, Rolls-Royce Ltd., *Associate Fellow*): It was gratifying to see the pilot accepted as a vital cog in the machinery of producing aircraft which represented an increasing proportion of the potential wealth of this country. The Royal Aeronautical Society had appreciated the contribution of the test pilots of today, and had opened its ranks of Associate Fellowship to those with the requisite experience and ability.

Technically the lecturer had presented facts rather than opinions, perhaps from a perspective not always appreciated by the designer, and as such they must be considered as a contribution to the art which was fully appreciated by all present at the meeting.

It was his experience recently—not in this country—to fly an aeroplane with considerable sweepback and a fair amount of tyre loading; a cross wind component limit was set on that aircraft which was well justified, because when landing at approximately the limit of cross wind the shielding of the lee wing was most noticeable, compared with that of non-swept aircraft. He wondered if that were borne out by Squadron-Leader Waterton's experience with deltas.

On the problem of the physical forces which had to be applied to the controls of an aircraft when in combat, certainly during the 1939-45 War there was a grave risk of a pilot's mental acuity being destroyed by the very large forces which had to be applied, and he could suffer from physical fatigue very quickly. Would the author support his view that it was better to educate pilots to appreciate the structural limitations of the aircraft? In many cases the pilot's physiological reactions would set the limit at low altitudes; high altitude would look after itself, because large forces in any of the planes would simply stall the respective controls.

The problem of changing the focus of the eye at high altitudes from objects at great distances to those within the cockpit, was one of power of accommodation, and he believed that the biggest contribution to its solution would be to have the dashboard at a greater distance from the pilot than was customary in some modern aircraft. He suggested that 3½ ft. was about the minimum distance at which the eye could be expected to focus; the difficulty of focusing from infinity to 2 ft. was about twice as great as that of focusing from infinity to 3½ ft., and the problem was not so much the shortening of the focus as the re-lengthening of it afterwards. He strongly supported the lecturer's plea for smaller instruments, because when one was flying on instruments one's vision was concentrated entirely in the cockpit, and the problem of re-focusing no longer arose.

Engine manufacturers had gone to great expense and trouble in trying to achieve an engine which could not be mis-handled in combat. Aircraft, however, still retained dangerous aerodynamic characteristics which would undoubtely result in many casualties in the circumstances of wartime trained pilots. Had the aircraft manufacturers in mind a means of limiting the aircraft speed when approaching dangerous flying conditions, such as by the automatic application of retardation by dive brakes?

He emphasised the importance of fitting warning lights; it was a mystery to him why the excellent stencilled warning lights which were fitted in Rootes' motor cars were not adopted for aircraft. The indications could be very simple; for example, the letters "L.P." would mean low pressure, the words "fuel" or "oil" could be spelt in full, and so forth. No problem would arise on the standardisation of the warning light bulbs, because the stencilling was on the glass and a standard bulb behind it would suffice. Would the lecturer be prepared to support the plea for the use of these very simple cockpit devices?

On the question of standardising components, to a large extent the standardisation of engines had been achieved already.

W. E. W. PETTER (Folland Aircraft Ltd., *Fellow*): He welcomed the reference to the importance of stability and control in the transonic region. He agreed with the pilot that a high standard here was absolutely essential and that without it sheer speed would be useless. There was room for considerable improvement in this direction and the "flying tail" would be essential for future transonic fighters.

The importance of thin trailing edge controls was now generally recognised and he did not agree that power control on all surfaces would be necessary, provided that the aircraft were small enough. It was particularly interesting that the MIG.15 used manual operation on all controls, although unfortunately they were unaware how effective this was at high speed.

Squadron-Leader Waterton was quite right to draw attention to the great importance of small irregularities on handling qualities at high speed, and close control of contour during manufacture would in future be just as important as control of main pick-up points in the jigging and tooling of high speed aircraft, and would be hard to achieve. So far as thick skins were concerned there had already been a move in this direction, but this had only just kept pace with the greatly increased suction and pressure which skins had to support, and therefore there had not been much opportunity to cut down internal stiffening.

The need for the production of the cheaper and simpler fighter, was increasingly recognised, but he did not consider that the standardisation of equipment would make any great contribution. Indeed, quite frequently a simplification or lightening objective required development of a new piece of equipment to be simpler, smaller and lighter than that which had gone before. The golden rule, he considered, was to eliminate everything which was not absolutely essential; for example, why could not the engine makers evolve fuel systems which did not demand booster pumps in the aircraft fuel tanks? The necessary pressure could be provided by an air system, were it not for the fuel system's over-sensitivity to air in the fuel, which required the introduction of an electrically-driven churn to remove air bubbles! Going further, were the large number of compression and the second turbine stages really necessary on engines designed for short flight duration?

On the aircraft side it had been found that landing flaps could be omitted, provided that adequate drag were available for landing, with very little increase in landing speed in the case of the thick swept wing. The decision as to whether two or four guns were necessary made all the difference in aircraft size and complication due to the snowball effect whereby useful payload was not multiplied up 8 or 10 times in the finished fighter aircraft.

The simple fighter of small size would never be a stripped down version of the standard machine; like the Austin 7 in the car range, it must be something designed from scratch for a particular purpose with all the *essential* features, albeit in simplified form, of the larger model. Everything from the wheels upwards had to be designed down to meet the new smaller and simpler conception.

W. WOOD: On manual controls for aircraft at supersonic speeds, did the lecturer feel that designers had gone far enough by way of research into the design of aerodynamic surfaces before calling in the aid of boosters for controls?

D. L. ELLIS (English Electric Co., *Fellow*): The lecturer had been fairly gentle in his criticism. He had referred to the days of the Camel; at that time there was not enough known about aerodynamics to allow a designing firm to keep one man occupied full time and so there were no Aerodynamics Departments to criticise. Present day Departments might be 50 or more strong and they made use of every available device for research and test. The latest development was the application of electronic methods in computing and flight testing, particularly in dealing with the vibration problems associated with high speeds. An important development during this period had been the closer interlocking of the different aspects of design; typical of this was the treatment of aeroelastic effects, in which an aerodynamic load caused structural distortion, which, in turn, modified the load and so on. At one time the errors in estimating these loads were greater than the changes due to distortion and so each subject could be treated independently. Now the effects of interaction between the loading, strength, stiffness, effects of engine installations and so on, were known to some extent and must be allowed for in the design of high speed aeroplanes. In other words, the design of the whole aeroplane must be treated as one problem; and he defied anybody to draw a dividing line between aerodynamics and thermodynamics.

Generally in engineering designing, be it a locomotive, a watch, an aeroplane, or any other machine, they had to contend with Nature. They had to bring into account the force of gravity, pressure and density of the air, the physical qualities of the materials used and so on, and usually Nature demanded a high price for any success she allowed them to achieve. Now, however, it looked as if she might be relenting a little because when they were capable of designing jet engines and aeroplanes which could achieve level supersonic speed, the increase of thrust with speed might possibly approach the increase of drag with speed; the possibilities of this were exciting and not a little frightening.

N. E. ROWE (Chairman of the Branches Committee, *Fellow*): He congratulated the Derby Branch on having organised such a splendid gathering to welcome the first main lecture of the Society to be delivered in Derby. It was gratifying to the Council, and particularly to the Branches Committee, because they were anxious that the Branches should make progress and feel that their activities represented an extremely important part of the work of the Society and were supported by headquarters.

The venture of bringing the Society out to the Branches had turned out very well and he believed it was adding great strength to the Society as a whole, because the members of the Branches were given the opportunity to hear main lectures, which was of advantage to them and afforded them encouragement.

He offered to the Branch the Society's deepest sympathy in the loss it had sustained by the death of its Honorary Secretary. He was a man of great ability and great enthusiasm, and one had hoped that he would have remained Secretary of the Branch for a long time, for he had the work so deeply at heart.

They had had a stimulating lecture by a most proficient specialist. Squadron-Leader Waterton had made points which he thought had not been made before, he had made clearer matters which had not previously been brought so forcibly into the open and had emphasised the problems that lay ahead in the very high speed range of flight. He had done that with a modesty which was most becoming in a man of his great knowledge.

In his experience those who possessed the greatest knowledge were always the most modest; they seemed to know so much that they appreciated how much they did not know, which was one of the striking characteristics of great men.

Contributed: There were many points on which one would like to comment; doubtless many would feel the same, and he would confine his comments to those which he personally thought were most important.

The author said that in Great Britain they had thrown a lot on the pilot to get the best out of their aeroplanes. That was undoubtedly justified by the facts, but it would be wrong to assume that it was a conscious objective of designers and others concerned in research and development. In fact, the first and essential characteristic of an interceptor fighter was the highest possible performance, and designers and others concerned were preoccupied with this in the middle thirties just as they were today. Then, as now, interception of a relatively high and fast enemy, of whom they had the minimum of warning from these shores, was the challenge, and the solution to the problem put the very highest demands on superlative performance. About the same time it was generally held that the highest manoeuvrability was obtainable when the aircraft had approximately neutral stability about all axes. They knew now that it was not necessarily so; one must remember that there had been a very great advance in the knowledge of the theory of stability and control, in design techniques to obtain high manoeuvrability, and in the understanding of structures to obtain this without undue increase in structure weight. Hence he thought that the qualities the author criticised were intrinsic in the design approach and it was not a matter of "making do."

The author clearly expected the "dog-fight" to be a feature of air operations in a future war. If this were correct, and he thought it was, it would be interesting and of great value, if they could have his views of the emphasis he would give to this aspect of performance in the basic design and whether he would be prepared to compromise other features, for example climb, ceiling or maximum level flight, to achieve good "dog-fighting" ability. The author discussed round the problem in his lecture but rather begged the question by such remarks as "provided that lift coefficient does not fall off with Mach number" and "lowering the stalling speed by 20 to 30 knots" when discussing the advantages from lower wing loadings.

The author made clear the increase in piloting problems which came in the course of nature from high speeds, high altitude vision difficulties and so on, and one was impressed by the need to cover the elementary stages of these effects in the course of early training. It would be of great interest to have his views on this matter, the stage in training at which this could be done and the effects which it was most important to demonstrate and experience in training.

He was most interested in the problem of focusing at great heights. Was this problem really one of focusing, or was it not the result of the relative light intensity outside and within the cockpit? He suggested that the answer to this problem was in a more intense illumination of the instruments within the cockpit, without glare, and he would welcome his views on this.

Having studied the paper, he offered his very sincere congratulations and best thanks for a most stimulating and up-to-date account of high speed problems as experienced by the pilot. It was of immense value, since it was the result of applying a critical intelligence to personal experience in full-scale conditions.

Squadron-Leader Waterton

SQUADRON LEADER BAILEY: On the question about the cross wind characteristics of the delta, he could speak only of the Javelin as to the actual wind velocity; it was of the order of 20 knots at 90°. Initially, on the unstick, there was a very slight tendency for the lee wing to go down, but that was easily held. No particular difficulties were experienced when landing, provided that one did not try to achieve the lowest possible touch-down speed; it was better to fly a little faster, keep incidence low and "fly on."

He was 100 per cent. in agreement with Squadron-Leader Bailey's remarks on the fact that a pilot's fighting ability could be seriously impaired by the forces he had to impose in controlling his aeroplane, and in addition he drew attention to the forces imposed under *g*. Another factor was that of personal comfort in respect of temperature. It was a very common experience during the last war for pilots to be completely fatigued after a few sorties and even today pilots did not get the deal which the Americans had with fully powered controls. After tugging a Service aircraft around in an air fight or in the course of aerobatics for 10 or 15 minutes one had had quite enough, and he felt, with Squadron Leader Bailey, that a very marked increase in fighter efficiency could and would result if the job were made much simpler and if less physical effort were involved.

He rather doubted that pilots could be made to appreciate the structural limitations of aircraft; it meant asking a little too much, certainly under conditions of combat or of high emotional stress. For that reason he felt that some indication was needed on the control to the effect that "so far was enough and more was too much."

While he agreed with Squadron Leader Bailey's remarks about focusing at high altitudes and the problem of moving instrument panels, he felt that perhaps the latter was not practicable. The windscreen too would have to be a greater distance away, or it would impose too great a problem on the designer as to lighting and space. Further, quite a lot of the instruments and instrumentation required adjustment, and it would mean a further complication if the panel were not within the reach of one's hands.

The answer might be the provision of warning lights in different colours, which would come on when required, so that one would not have to search; one of the troubles with instruments at present was that one had to look for both instruments and warning lights.

If the general stall and compressibility characteristics of the aircraft were satisfactory the pilot received warning and could act accordingly. If an aeroplane were vicious to start with, however, he was not sure that to give warning was the right answer. The real answer was to see to the characteristics of the aircraft itself, particularly at high altitudes. At high altitudes the rate of change of condition could be extremely rapid: some aeroplanes had to be put into practically a screeching dive to get compressibility factors at low altitude; it was a different matter at 40,000 or 50,000 ft.

No doubt automatic speed restriction devices could be provided, but the general requirement was to try to get away from all limitations, in other words to have an aircraft which one could put on its back and push right down from 50,000 ft. or more without bother. It appeared that with modern fighter aircraft they were in sight of doing that. People had been advised not to use air brakes when in trouble with the Meteor, because there had been some rather disturbing events through rapid change of trim. If the aircraft were generally docile and easily handleable, throttling back was the effective answer.

MR. PETTER: It was very interesting to hear a designer of the reputation of Mr. Petter facing up so strongly to the case for stability and control.

He had not used tail parachutes; although he had seen them, he did not like them; they were not part of the aircraft and he considered that they constituted a bit of a menace and a nuisance in operation. It was necessary to have proper sections for storing and handling them generally; if one landed away from base, without those facilities, one was in something of a mess. Had the possibility of an overshoot at the last moment been considered and in such circumstances what was the action as to jettisoning the tail chute and the provision of another for a second attempt? He would prefer the simple flap.

As to thick skins, it was to be hoped that a different form of construction might be used which would employ many fewer internal members with a thickening of the skin to the extent of perhaps using plate construction with relatively few, but sturdy internal stringers and ribs.

As a limited weapon the small simple light fighter was appreciated. Firstly, however, it must have enough armament to carry out its role and secondly, enough performance and handling ability to get to its opponent. He was a great believer in the relatively cheap centrifugal engine with which the "Mig" did not appear to fare too badly.

MR. WOOD: Certain people had tried but had failed to solve the problem aerodynamically, and he believed that was the main reason why there had been such a lot of poor controls in the past. He was sure that more could be done by the way of aerodynamic research in relation to controls. The designers of the MIG.15 seemed to have dealt with the problem, and the question was, how well had they done so? Did the machine hurtle down supersonically? Did it fly the pilot or did the pilot fly it? He did not know; if the latter were the truth, well and good, but if it were the former, then it was nothing on which to put one's money.

His view that more could be done on the aerodynamic side applied to the aeroplane as a whole. The

DH.108 had instability troubles, but it had achieved a fantastic speed with an engine of relatively low power, and that fact seemed to have been lost on the whole Aircraft Industry. Had a T-type horizontal tail been evolved and put on it they could have had, years ago, an aeroplane of extremely good performance on extremely low power.

MR. ROWE: He felt that his contention that they had thrown a great deal on the pilot in Great Britain was borne out and amplified by Squadron Leader Bailey's remarks and would be by most pilots. He certainly did not mean to imply that it was a conscious objective of designers to throw a lot on the pilot, but rather a lack of appreciation of the actual piloting problems and their effect on the operational efficiency of the combination of pilot and aircraft. Whether or not the fault lay with pilots themselves in not stating their views sufficiently strongly in these matters, whether or not such representations were not sufficiently clear and unanimous or whether, as he strongly suspected, they were not considered of prime importance, was difficult to know, but the fact of the matter was that much could be done to improve things.

He did believe that dog-fighting would always be with them as long as there were conditions involving fighter against fighter. There was, however, a further aspect of "dog-fighting ability" and that was the high altitude case of fighter *versus* bomber. That involved control and manoeuvrability to a high degree under conditions of low A.S.I.s and both moderate and high Mach numbers, and was behind the remarks of increasing the usable speed range of the aircraft by lowering the stalling speeds. That, of course, also applied for bomber aircraft taking evasive action, as well as formation and tactics at great height. It was difficult to state whether climb, ceiling or maximum level flight speed could be sacrificed to achieve good "dog-fighting ability" unless one knew in detail the performance of the opposition and the ground control facilities and early warning systems at one's own disposal. However, he did feel that, particularly at high altitude, an aircraft without good control and turning circles over a useful speed range would suffer as either a fighter or a bomber. He personally, did not believe that sheer level or diving speed was the whole answer by any means, since it might well be virtually meaningless without the other capabilities; on the other hand the compromise to be made must leave a very real margin of fighter overtaking speed against enemy bombers. Low wing loadings, which made for turning ability, should also show to advantage in both ceiling and climb.

It was thought that very useful practice and training in high altitude flight could be given to young pilots by making them practice flying at near the ceiling of trainer aircraft, even if the aircraft were piston-engined. The low A.S.I.s, limited speed range, proximity to the static or dynamic stall and decreased stability most types exhibited would be invaluable for really high altitude handling problems. As to vision, perhaps a useful exercise would be that of trying to pick up other aircraft at 10,000 ft. to 15,000 ft. on the cloudless, sunny, yet very hazy days that were often experienced in the United Kingdom. Both those exercises might well be done at an advanced F.T.S., A.F.U. or O.T.U. stage where further practical experience might be gained in formation and dummy attacks, at near the ceiling of the particular aircraft employed.

He believed that better illumination of cockpit instruments with greater contrasts between dials and markings would help, but still would not solve the focusing problems.

He was most honoured to have had the opportunity of addressing the Derby Branch of the Royal Aeronautical Society; from what he had gathered, if not exactly popular, his "talk" had aroused some discussion and thought, which after all was its main intent.

He had been criticised for taking an unkind view of British aircraft and criticising them unfavourably with German and American aircraft. He would like to point out that he was well aware that, in many respects, British aircraft had many superior points to both of those nations' aircraft but there seemed to be a certain amount of self satisfaction evident these days and he felt that it was time that someone pointed out publicly the "not-so-rosy" side of the situation. Naturally this had not been popular but he felt it was necessary for the general good since they often "spoiled a good ship for a ha-porth of tar." He considered that the combination of average pilot and aeroplane should be considered the potential and effective worth of the aeroplane and not only the performance of the aeroplane itself, which, because of handling problems, could not always be realised by the pilot to anything like its theoretical extent.

Lifing of Aircraft Equipment and Instruments

by

W. TYE, O.B.E., B.Sc., F.R.Ae.S., and H. B. CUNDALL, B.Sc., A.F.R.Ae.S.
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1. Introduction

The practice of removing aircraft items for overhaul at specified periods has gradually extended in recent years, so that most types of equipment and instruments have come to be dealt with in this way. The period between overhauls is often called—somewhat inappropriately—the life of the item and, for the sake of brevity, this is the word used in this paper.

The primary object of this procedure is to remove the items for overhaul before defects occur. If this is achieved, two benefits accrue:—

(*a*) the defect rate is minimised, with consequent improvement to safety.

(*b*) the operator does the work at convenient times at the overhaul base instead of being driven to do work when and where defects occur.

At first sight one would suppose that by reducing life, and hence by making more frequent planned replacements, one could not fail to reduce the frequency of occurrence of defects. In fact, it seems probable that, in many instances, this is not so. Rather, it seems that the length of the overhaul period has little or no bearing on the defect rate. Thus, in many cases, lifing of items does not achieve the hoped for benefit.

The purpose of this paper is to describe a semi-mathematical examination of the problem that has recently been completed and to which reference has been made by Mr. R. E. Hardingham in the Eighth British Commonwealth and Empire Lecture[1]. The conclusions reached would have caused surprise a few years ago, but recent trends in the practical application of "lifing" systems have all led in the same direction.

Acknowledgments are due to the British European Airways Corporation whose excellently prepared and analysed defect records formed the practical evidence on which this paper depends.

2. Examination of Defect Records

Defects appear to fall into three classes:—

A. Those which arise in a random fashion, and which are as likely to appear early or late in the use of the item.

B. Those due to wear, or more rarely fatigue, which, beyond a certain number of hours of use, occur with increasing frequency.

C. Those which seem to spring from a fault in manufacture, overhaul, transport, handling or installation, which show up early in the use of the item.

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Figure 1 shows defect records of these three types. In each of these the defect rate, expressed as defects per 1,000 item-hours, is plotted against hours of use since overhaul. The records shown in (*a*) and (*b*) are ones in which Class A defects predominate, the items failing as frequently early in life as late in life. In (*c*) there is a gradual rise of defect rate as the items age, presumably because some failures of Class B as well as those of Class A are occurring. In (*d*) the defect rate is falling as the items age, some items failing as a result of Class C defects.

The defect records of a large number of items have been examined and the remarkable conclusion is that most items—at least up to the lives so far permitted—exhibit defect records of the kind shown in Fig. 1 (*a*) and (*b*). A few show a rising defect rate as in (*c*) and very occasionally an item shows a falling defect rate, as in (*d*).

3. Effect of Life on Defect Rate

The fact that a large majority show this characteristic of a constant defect rate is of considerable

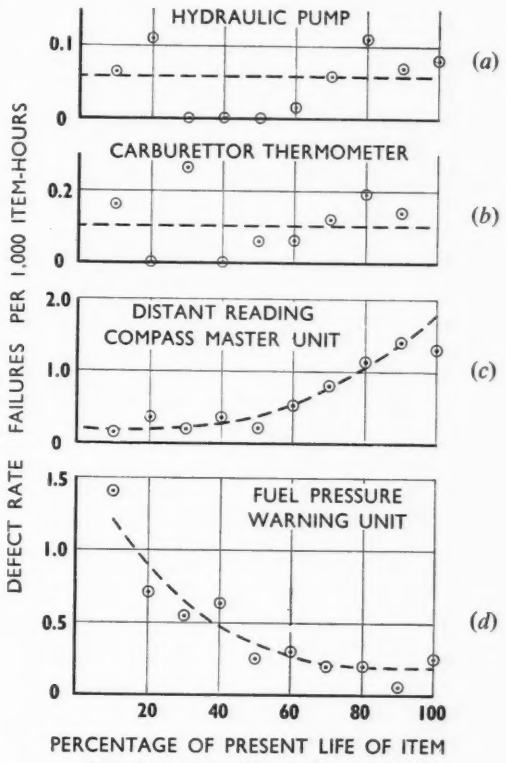

FIGURE 1. Examples of defect records.

practical importance, because it means that had the item had a shorter life imposed (*e.g.* a half, or a quarter, or even one-tenth of the present values) there would have been *no reduction in defect rate*.

It may be argued that if the lives of such items were raised beyond the present values, there might be a rise of the defect rate. This would occur if defects of Class B (*e.g.* due to wear) began to appear with increasing frequency. However, as will appear later in this paper, it may well be that before the items reach the hours at which wear becomes troublesome, the majority of items would already have failed for other reasons. If this occurs, then the increase of defect rate beyond a certain point would still make little difference to the overall *average* rate of replacement of defective items.

4. Numerical Example

In the Appendix, the mathematical relationship is established between rates of occurrence of defects, rate of replacement of time-expired items, and life. It may aid understanding of the matter to consider a numerical example. Take the usual case in which the likelihood of a defect is constant regardless of the number of hours of use of the item. This means that the total number of defects occurring will be directly proportional to the number of item-hours of use. Suppose that the defect rate is

1 defect per 1,000 item-hours.

Consider 100 items starting together to run until they fail. In the first 100-hour period roughly 10,000 item-hours are run, and hence 10 defects would occur. (This is an approximation but illustrates the general point well enough; *see* the Appendix for the exact calculation.)

In the second 100-hour period, 90 items are running, giving 9,000 item-hours, and hence 9 defects occur leaving 81 survivors. Thus, in each 100-hour period 10 per cent. of the items fail.

The result of this kind of calculation (but made in accordance with the exact method of the Appendix) is given in Fig. 2. It will be noted that since, by definition, the defect rate is constant, the total number of defects is proportional to the total number of item-hours of running. Hence, the curve of Fig. 2 represents both total defects and total item-hours.

The next point to consider is the total rate at which the surviving items are removed for overhaul. Reference to Fig. 2 shows that if the life is fixed at 300 hours, 26 items fail and 74 survive to be removed for overhaul. Up to this time 26,000 item-hours have been run, so the removal rate for overhaul is 74/26,000 or 2·8 items per 1,000 item-hours. Similarly, if the life is 1,000 hours, the removal rate is 0·6 items per 1,000 item-hours; while if the life is 3,000 hours the removal rate falls practically to zero.

It is therefore clear that in these cases, where the probability of occurrence of defects is unaffected by hours of use

(*a*) the average rate of removal of defective items is independent of the life figure (as would be expected);

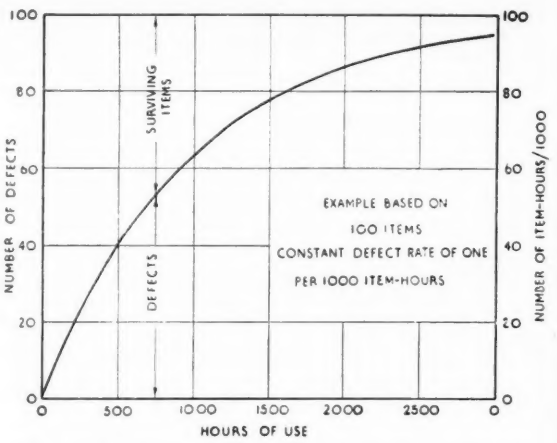

FIGURE 2. Numbers of defects and surviving items plotted against hours of use.

(*b*) the average rate of removal of items for overhaul is large if life is small, falling rapidly as life is increased to a moderate value, and thereafter falling very slowly as life is further increased.

This example may appear a little unrealistic in the respect that we considered a steadily reducing total number of items, whereas the operator keeps a constant number of items in use all the time. This does not alter the validity of the conclusions so far reached, but the numerical results may be expressed in a more obvious form.

Suppose, for example, that the operator has a fleet of 50 aeroplanes, each carrying one item of a particular kind; and suppose that each aircraft flies on the average 2,000 hours per annum. Thus, the total utilisation of the item in one year is 100,000 item-hours. With the defect rate assumed at the beginning of this section, there will be 100 defects in this period, irrespective of the life fixed for the item. If the life is fixed at 300 hours, there will be 280 time-expired items removed for overhaul; and if the life is 1,000 hours, there will be 60 items removed for overhaul. With a life of 3,000 hours, there will be practically zero (actually 5 items) removed for overhaul. If we assume that the amount of work done by the operator is the same whether the item is removed because it is defective or because it is time-expired, then the total work done is proportional to 380, 160 and 105 for lives of 300, 1,000 and 3,000 hours respectively. If the work on a defective item is twice that on a time-expired item, the three corresponding figures are 480, 260 and 205. In either case the reduction of work with increase of life is striking.

5. The General Case of Constant Defect Rate

In the Appendix a calculation is made of the general case corresponding to the particular numerical example given above.

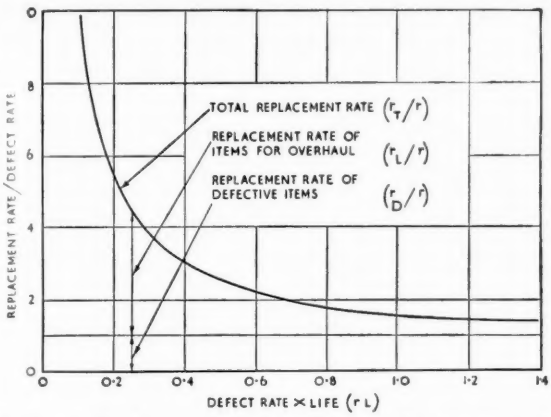

FIGURE 3. Replacement rate of items for overhaul in terms of life, assuming defect rate is unaffected by hours of use.

If r is the defect rate which is assumed to remain constant, irrespective of hours of use,

r_L is the average replacement rate of items for overhaul at the end of their life L,

it is shown that

$$\frac{r_L}{r} = \left(\frac{e^{-rL}}{1-e^{-rL}}\right).$$

The relationship of r_L/r with rL is shown plotted in Fig. 3.

It will be seen that while the number of items removed because they are defective remains constant irrespective of life, the number of time-expired items removed falls as the life L increases. When rL is small, of the order 0·1, an excessive amount of work is done in removing time-expired items, while if rL is of the order 1·0 the work done is modest.

It will be noted that whether one should view life as "long" or "short" depends on the defect rate. For example,

if the defect rate is once per 1,000 item-hours, a life of 100 hours ($rL=0{\cdot}1$) is short, while a life of 1,000 hours is long;

if the defect rate is once per 10,000 item-hours a life of 1,000 hours is short, while a life of 10,000 hours is relatively long.

6. An Example of Increasing Defect Rate

Some items show a defect rate which increases with hours of use. Others, which show a constant rate up to the hours of which there is experience, may display an upward trend if run to higher hours. A simple case of increasing rate can be assumed as follows. Suppose there are initially 100 items which begin to run at the same time; suppose that in each successive 100-hour period a constant *number* of defects occur. Thus

10 items fail in the first 100-hour period leaving 90 items;

10 items fail in the second 100-hour period leaving 80 items;

10 items fail in the period between 900 and 1,000 hours.

In this example during the first 100-hour period there are approximately 10,000 hours of use, so that the *initial* defect rate is one per 1,000 item-hours. In the period between 500 and 600 hours, there are 50 items at the beginning of the period, and hence a total of approximately 5,000 item-hours. Thus the defect rate has risen to 2 per 1,000 item-hours. A defect rate of this kind is shown plotted in Fig. 4, and it will be observed that it rises slowly at first, but eventually approaches infinity. This is reasonably consistent with practical results obtained in certain cases.

The results of a generalised calculation (of which the foregoing is a particular example) are shown in Figs. 4 and 5. The terms used are

r_0 is the initial defect rate of new items.

r is the defect rate of items after t hours of use.

r_D is the average rate of replacement of defective items when the life is L.

r_L is the average rate of replacement of items for overhaul when the life is L.

T is the time taken for all the items to fail by defect, no items being removed for overhaul.

Figure 4 shows that at half time ($t/T=0{\cdot}5$) the initial rate has been doubled and thereafter begins to rise quickly until it reaches infinity at $t/T=1{\cdot}0$. Fig. 5, however, shows that the *average* rate of replacement of defective items increases very slowly with increase of life L. If L is equal to or greater than T, all items have failed before any are removed for overhaul. This is equivalent to abolishing life altogether. If this is done, the *average* rate of replacement of defective items is only twice the value it would have been if the life were extremely short. On the other hand, the rate of replacement of items for overhaul is very high if life is short, but falls to zero if the life fixed exceeds T.

Although the particular form of rising defect rate assumed in this example has no special significance, it suggests strongly that even if the liability for defects to occur increases rapidly with hours of use, the average replacement rate of defective items is not seriously affected by increasing the life.

It can be shown for this particular form of rising defect rate that if the work done per defective item

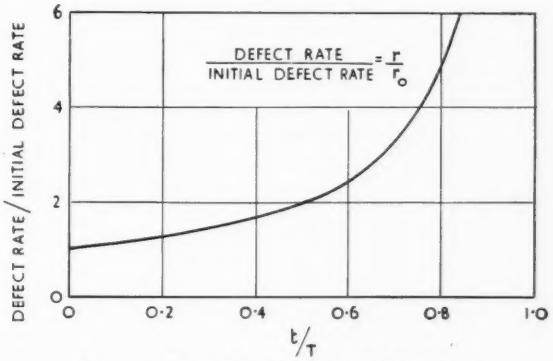

FIGURE 4. Example of increase of defect rate.

exceeds the work done per time-expired item, there is a particular life which gives the absolute minimum amount of work. For instance, if the labour involved per defective item is twice that per time-expired item, the optimum life (for minimum total work) occurs when the life L is in the region of $0{\cdot}7T$. It therefore follows that even with a sharp increase of defect rate the best overall results may still be obtained by a fairly high life.

It is, of course, possible to conceive an even more rapid increase of defect rate. For the sake of examining an extreme possibility, consider an example in which the defect rate initially has a constant value r_0, but after a number of hours of use t_1, the rate is immediately increased to ten times its initial value. If the life L is less than or equal to t_1 then the replacement rate of defective items r_D is equal to r_0. If the life L exceeds t_1 an increase of replacement rate obviously occurs. It can be shown that

(*a*) if the hours of use at which the sudden rise of defect rate occurs is small, corresponding to $r_0t_1 = 0{\cdot}1$, then if the life L is $1{\cdot}5t_1$, the average replacement rate is $3{\cdot}5r_0$;

(*b*) if the hours of use at which the defect rate rises is large, corresponding to $r_0t_1 = 1{\cdot}0$, then if the life L is $1{\cdot}5t_1$, the average replacement rate is $1{\cdot}5r_0$.

The significance of these results is that even if the life is established above the point at which the defect rate rises, and even if a very large (in this case tenfold) increase occurs, the average replacement rate of defective items is not catastrophically increased. Moreover, provided that the increase of defect rate does not appear till late in hours of use, the increase of replacement rate is small. Hence it is safe to explore the effects of increase of life without fear of catastrophic increases of the overall replacement rate of defective items.

7. Some Practical Observations

Defect rates for most instruments and items of small equipment lie in the range 0·05 to 0·5 per 1,000 item-hours. Until recently lives have been established between 500 and 3,000 hours, generally speaking the longer lives being associated with the lower defect rates. A fairly typical case would be a defect rate of 0·1 to 0·2 per 1,000 item-hours and a life of 1,500 to 2,000 hours. Hence, a typical value of rL would be about 0·3. Up to these hours many items have shown no detectable increase of defect rate with hours of use. In recent months, for those items in which wear is unlikely to result in an increase of defect rate, a move towards very substantial increases of life has been made.

The potential reduction in work can readily be seen from Fig. 3. If the life was doubled, giving in the typical case an increase of rL from 0·3 to 0·6, then the total number of items removed would be reduced by over 40 per cent. To give a further example, supposing that the annual utilisation of an item is 100,000 item-hours and the defect rate is 0·2 per 1,000 item-hours, then the corresponding number of removals of items per annum, assuming the defect rate is unaffected by increasing life, is as shown in the table which follows.

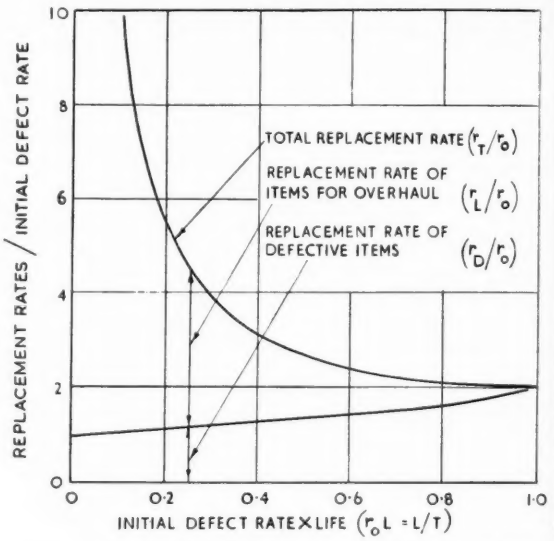

FIGURE 5. Replacement rates of items for overhaul and defective items, assuming the defect rate is that shown in Fig. 4.

Life	*rL*	*No. of defects*	*No. of life-expired items*
1,000	0·2	20	91
2,500	0·5	20	31
5,000	1·0	20	12

8. Conclusions

(*a*) Many items fail in a random fashion, such that the likelihood of failure is the same early in hours of use as late in hours of use.

(*b*) When this is the case the life figure established makes no change in the number of defects which occur.

(*c*) If beyond a certain number of hours of use the defect rate increases, the higher the life established the greater will be the number of defects, but generally speaking, even if the defect rate rises rapidly after a certain number of hours of use, moderate increases of life beyond this point will not seriously alter the total number of defects. This is particularly the case when the onset of the increasing rate does not occur until a high value of rL is reached—most of the items already having failed in a random fashion.

(*d*) If the life is low in relation to defect rate (*e.g.* $rL = 0{\cdot}2$ or less) the number of replacements of items for overhaul will be excessive.

It follows from these conclusions that the practical procedure to follow is:—

(*a*) Find from the defect records whether the defect rate is substantially constant with hours of use up to which there is experience (*i.e.* up to the

currently established life). Also determine the defect rate r and hence rL.

NOTE: In examining the defect record, it should be remembered that a constant defect rate means that the absolute number of items failing decreases with increase of hours of use (*see* Section 4).

(*b*) If there is no observable rise in defect rate and if rL is already large, there is little to be gained and little to be lost by altering the life.

(*c*) If there is no observable rise in the defect rate and if rL is small, a substantial increase of life is desirable. The magnitude of the increase must depend, of course, on engineering considerations. If an increase in life seems likely to lead to increase of defect rate, a modest increase of life by 25 per cent. or 50 per cent. should be tried first. If there is no reason to expect increase of defect rate, and particularly if the item is not vital to safety, a bolder increase (*e.g.* doubling or trebling) might be tried.

(*d*) After such a first step further defect evidence should be collected before further changes are made. Also it is important to keep a watchful eye on the strip examinations to see whether any deterioration in condition is occurring.

One final observation may be made. The fixing of short lives is one of the ways in which an attempt has been made to keep defect rates down. If in particular cases this method proves fruitless, it drives one back to the fundamentals of design and construction to see whether basic improvements would result in reduced defect rate. It may indeed be a somewhat healthier outlook for the designer and constructor of the items to work on the assumption that lifing will give very little protection.

APPENDIX

Notation

r = defect rate pertaining to time t
r_0 = initial defect rate of new items
r_D = average rate of replacement of defective items when life is L
r_L = average rate of replacement of items for overhaul when life is L
r_T = total replacement rate $= r_D + r_L$
L = life
T = time taken for all items to fail by defect
t = time of running of a particular item
n = number of items at time t
n_0 = initial number of items

IT IS ASSUMED THAT r IS CONSTANT

Number of defects δn occurring in time δt is $nr\delta t$.
Rate of change of number of items is

$$\frac{dn}{dt} = -nr.$$

Therefore
$$\frac{1}{n}\frac{dn}{dt} = -r$$

$$\log_e n = -rt + A.$$

When $t=0$, $n=n_0$.
Therefore $A = \log_e n_0$
and $\log_e n - \log_e n_0 = -rt.$
Hence
$$n = n_0 e^{-rt}. \quad . \quad . \quad . \quad . \quad (1)$$

Equation (1) shows the proportion of items surviving at any time t. When plotted against t for particular values of n_0 and r, the curve of Fig. 2 is obtained.

The total number of item-hours of use up to time t is

$$U = \int_0^t n\,dt$$

$$= n_0 \int_0^t e^{-rt} dt.$$

Therefore
$$U = \frac{n_0}{r}(1 - e^{-rt}) \quad . \quad (2)$$

The number of defects which have occurred by time t is

$$n_0 - n = n_0(1 - e^{-rt}) \quad . \quad . \quad (3)$$

Thus the average rate of replacement of defective items is

$$r_D = \frac{n_0 - n}{U} = \frac{n_0(1 - e^{-rt})}{\frac{n_0}{r}(1 - e^{-rt})} = r.$$

(This is as it should be since r is constant.)

The rate of replacement of items for overhaul if life is L is

$$r_L = \frac{n}{U} = \frac{n_0 e^{-rL}}{\frac{n_0}{r}(1 - e^{-rL})}.$$

Therefore
$$r_L = r\left(\frac{e^{-rL}}{1 - e^{-rL}}\right) \quad . \quad . \quad . \quad (4)$$

and the total rate of replacement is

$$r_T = r_D + r_L = r\left(\frac{1}{1 - e^{-rL}}\right) \quad . \quad . \quad (5)$$

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Some Aspects of Noise From Supersonic Aircraft

by

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SUMMARY:—The noise problem associated with an aircraft flying at supersonic speeds is shown to depend primarily on the shock wave pattern formed by the aircraft. The noise intensity received by a ground observer from a supersonic aircraft flying at high as well as low altitudes, is shown to be high, although it is of a transient nature.

A study of the shock wave patterns around an aircraft in accelerated and retarded flight is shown to lead to an explanation of the one or more booms, of short duration, heard by ground observers after an aircraft has dived at supersonic speeds.

The shock wave patterns associated with an aircraft flying in accelerated or retarded flight at transonic speeds are shown in certain cases to be very different from the corresponding patterns observed in steady flight. The significance of these results, with reference to problems of flight at supersonic speeds is briefly discussed.

1. Introduction

The aerodynamic noise emitted by high-speed aircraft has attracted increasing attention in recent years; it is already a serious nuisance and it is threatening to become worse.

It is known that the major noise, created by an aircraft travelling at subsonic speeds, is due to the jet and/or the propeller. In these cases most of the annoyance to the general public arises during running up on the ground, the take-off and landing. On the other hand the noise level produced at the ground from a jet aircraft flying at high altitudes is less than the average noise level of a busy city street. It is interesting to note that the noise level on the ground will in general be much greater for a single high-speed aircraft flying at low altitude than for a large formation of high-speed aircraft flying at high altitude, although in the latter case the time duration of noise will be extended.

When an aircraft is flying at supersonic speeds a shock wave pattern is formed around the aircraft. The shock waves, which are formed as a result of the aircraft speed being greater than the speed of propagation of the pressure disturbances created by the aircraft during its flight, envelope the sound waves created by the aircraft and its jet in the direction of motion. Hence a ground observer must hear the shock waves produced by an advancing aircraft before the noise from the jet. The sensation of noise caused by the shock waves, even when they are weak, is very much greater than that produced by other sources, although the time duration of the noise is in most cases very small. Examples of the sensation of noise caused by shock waves are provided by bullets, shells, missiles[24] and aircraft (at present) in dives. With aircraft, when the supersonic part of the flight occurs at high altitudes, one, two and sometimes more, "bangs" are heard by ground observers. Although the pressure changes received near the ground have not, as yet, been strong enough to cause damage to the human ears or to property there is understandably interest in the likelihood of these "bangs" being stronger when emitted from faster and low flying aeroplanes and missiles. Even if stronger "bangs" prove unlikely to reach the ground because of atmospheric refraction, the possible effects on other aircraft flying near a supersonic aeroplane must be assessed.

It will be shown that the explanation of the "bangs" and related problems with reference to the noise from supersonic aircraft, lies in an understanding of the shock wave pattern around the aircraft for uniform, accelerated and retarded flight. It is then possible for the relative importance of the height, speed and size of the aeroplane to be assessed and for the strength of the "bang" to be estimated.

Because of the limited amount of data available for shock wave patterns around bodies in unsteady flight some of the conclusions stated in this paper must be regarded as qualitative only and may need slight modification when more accurate data are obtained.

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Notation

a speed of sound
a_0 speed of sound in undisturbed air
c chord of aerofoil in Section 7, critical speed in water ($=\sqrt{(gh)}$) in Section 8, wave velocity in Fig. 29
d distance apart of shock waves in Section 7, diameter of body in Fig. 30.
f acceleration
g acceleration due to gravity
h depth of water in Section 8, height in Section 9 and Figs. 29 and 30
l body length, Section 7 and Fig. 30
l, m, n direction cosines, Section 6
M Mach number
M_0 free stream Mach number
n frequency, Section 3
p pressure
p_0 free stream pressure
r, θ polar co-ordinates, Section 6 and Fig. 11
R radius of pulse wave
t time
U_1 body speed
v wind velocity
V velocity
x, y, z Cartesian co-ordinates, Section 6 and Fig. 13
$\mathbf{x}$ position of observer
$\mathbf{y}$ position of acoustic source } in Section 3
y distance normal to aerofoil, Section 7
$2y_m$ aerofoil maximum thickness
α angle between the forward Mach cone and the acceleration vector
β angle of sound ray to ground normal
$\gamma=(\pi/2-\mu)$ in Section 6 and Figs. 12 and 14, ratio of specific heats in Section 8
δ fineness ratio of body
θ direction of flight path to ground normal, Section 9
λ wavelength
μ Mach angle
ξ angle of shock wave, Fig. 3
ξ, η, ζ Cartesian co-ordinates of flight path, Section 6 and Fig. 13
ρ radius of curvature of flight path
τ retarded time
ϕ total angle of sound ray to ground normal

2. Response of the Ears to Transient Pressure Disturbances

It is pertinent to consider briefly the response of the ears of a ground observer to transient pressure disturbances as a preliminary to a discussion on the noise emission from high-speed bodies in flight. The human ear is a highly selective frequency analyser, sound locator and an indicator of the loudness, pitch and the timbre of sounds. (*See* Reference 3 and the references quoted therein.) Thus an incident pressure disturbance, having a complex wave form is resolved by the listener's ear into its Fourier components and the sensation is that of a fundamental sound and a series of overtones whose intensities are greater or smaller than that of the fundamental. With continuous noise, whose spectrum is not "white" (*i.e.* continuous and uniform as a function of frequency) but peaks over a discrete band of frequency, the listener will, as a result of the Fourier analysis, sense the high intensity noise above the background, provided that the difference intensities and the bandwidth are within definite ranges. It has also been observed[4] that only two successive cycles are sufficient for a listener to determine the pitch of a pure note, at least up to a frequency of about 1,000 cycles/sec. In general, however, the duration of the note must exceed 0·01 seconds for accurate pitch determination to be made. In addition, for sounds of shorter duration, although the ear cannot detect the pitch, it continues to respond for about 0·01 seconds, and this response is commonly called the aftersound. Thus under normal conditions, two following sounds of short duration will not be distinguished one from the other, unless their time interval is greater than 0·01 seconds.

There is an upper limit of frequency of sound that is audible to the human ear and this limit is about 20 to 25 kilocycles/sec. But the ear will register a single pulse of short duration provided that the intensity is great enough. In all such cases, due to the aftersound, the duration appears to be about 0·01 seconds. For example an electric spark of one microsecond duration is heard as a crisp "chirp," whereas an intermittent spark triggered at the rate of 1,000 per sound is heard as a prolonged "chirp" of about 1,000 cycles/sec. pitch.

There appears to be little correlated experimental evidence between the aural sensation and a high fidelity microphone for transient disturbances such as shock waves. Records obtained from projectiles fired in air at supersonic speeds and at low altitudes indicate that the shock pattern associated with the projectile passes in less than 0·01 seconds, whereas the explosive (or gun) wave is of longer duration. From what has been stated already it can be seen that the ears will respond to the passage of shock waves, and will identify their amplitude and direction.

3. Doppler Effect

When a body is in motion relative to an observer, the observed pitch is different from the pitch of sounds emitted from the body or the flow field around the body. If the sound radiators, which are moving with the velocity $\mathbf{M}a_0$, where $\mathbf{M}$ is the Mach number and a_0 is the speed of sound in undisturbed air, send out vibrations of frequency n at the point $\mathbf{y}$, then the observed pitch[5] at $\mathbf{x}$ is

$$\frac{n}{1-\dfrac{\mathbf{M}(\mathbf{x}-\mathbf{y})}{|\mathbf{x}-\mathbf{y}|}}.$$

The frequency is increased for sound emitted forwards and decreased for sound emitted backwards. The Doppler effect applies equally well to each band of frequencies in the spectrum of noise emitted by a sound radiator.

It has often been stated that for a body moving towards an observer at rest, with unit Mach number, the apparent frequency of the emitted sound, as a result of

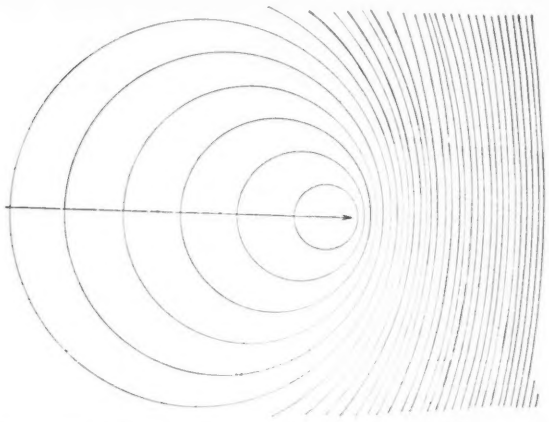


FIGURE 1. Source moving along a straight line with constant subsonic speed $M = 0{\cdot}8$.

Doppler effect, is infinite, and therefore outside the audible range. The *incorrect* conclusion is then drawn that at the instant the aircraft passes the observer the aircraft will not be heard. This remark is then, more often than not, followed by the *correct* statement that the noise, heard by the observer as the aircraft recedes, is at frequencies equal to half that of the sound emitted. This paradox only arises in neglecting (*a*) the sources of sound that are associated with the body in motion, and are not themselves travelling at the same speed as the body, and (*b*) the shock waves around the body, which arise from the pressure field of the body and its propagation, and are readily converted by the ear into noise.

4. Noise from Bodies at Subsonic Speeds

The sound emitted from a body travelling through the atmosphere may be classified under the headings external and internal. Internal sound includes the noise from engines, compressors, turbines and pumps and so on, whereas external sound includes the noise due to propellers, piston-engine exhausts[6], jets[5], boundary layers, wakes, tip vortices and to the pressure field associated with the body motion. An analysis of the noise received by a ground observer shows that the internal noise accounts for only a small fraction of the total noise. With high-speed aircraft, propulsion is usually by means of a jet and the noise emitted from the jet generally dominates the remainder of the noise, at least at subsonic flight speeds below the critical Mach number. Only this type of noise, in addition to that associated with the body pressure field, is considered here.

4.1. JET NOISE

The noise emitted from a jet arises from the turbulent motion[5] in the mixing region between the main flow near the jet centre, and the air at rest outside. The noise, which is strongly directional, is a function of the jet speed[7], temperature and diameter[8]. The intensity falls off approximately as the inverse square of the distance from the jet. For jets below choking, the emission is stronger in the downstream field (relative to the jet) and weaker in the upstream field. For jets above choking, the noise field is modified by the interaction of turbulence with the stationary shock waves[9] (relative to the jet exit) in the jet, and in certain ranges of frequency and pressure ratio the upstream radiation may be greater than the downstream[10].

4.2. PRESSURE FIELD DUE TO BODY MOTION

If a body starts from rest and is gradually accelerated until it reaches a uniform subsonic speed then at each instant each part of the body sends out pulse waves of small amplitude, which move with sonic speed. These waves are referred to, sometimes loosely, if graphically, as warning the air ahead that the body is approaching. (*See* Fig. 1.) Since at present subsonic body speeds are being considered, these waves will travel both upstream and downstream relative to the body. The complete system of waves is directional and a simple argument shows that their amplitude and wavelength will be respectively functions of the body volume and its length in the direction of motion. (On the rather crude assumption that the body may be replaced by a source-sink combination[1].)

The system of waves can be seen easily by dragging a two-dimensional body through shallow water at low speeds. It can be shown that the elevation and depression of the weak surface waves (apart from the capillary waves of small wavelength) correspond to the longitudinal wave motion produced by movements of a similar body through air. The analogy between shallow water waves and pulse waves in air follows from the fact that both have a speed which is independent of wavelength.

An approximate calculation[1] shows that in accelerated flight at high subsonic speeds the amplitude of the pressure disturbances at a large distance from the moving body is not negligible in terms of noise intensity. This problem, which relates to the calculation of the pressure history at a fixed point due to the motion of a body, needs further investigation.

5. Noise from Bodies at Supersonic Speeds

The sources of noise associated with a body travelling at supersonic speeds are similar to those at subsonic speeds except that, as already stated, the pressure disturbances created by the body during its motion form a system of shock waves around the body. With a jet-propelled body the main noise, at a large distance from the body, will be a combination of jet, wake and boundary layer noise and the noise due to shock waves.

5.1. PULSE WAVES, MACH WAVES AND SHOCK WAVES

When a body is flying at steady supersonic speeds the pulse waves, which are emitted continuously by the body during its flight, and which are moving at sonic speed relative to the local flow, can no longer propagate upstream since their speed is less than that of the body. The pulse waves which are emitted from an infinitely small body form envelopes and the surfaces generated are called Mach waves (*see* Fig. 2). A Mach wave across which there is an infinitesimal increase (decrease) in pressure is referred to as a compression (expansion)

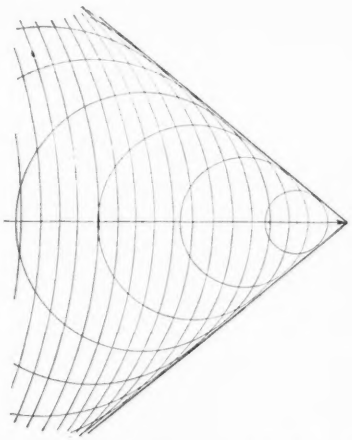


FIGURE 2. Source moving along a straight line with constant supersonic speed $M = 1{\cdot}6$.

wave. By definition, the velocity normal to a Mach wave is sonic. The angle the Mach wave makes with the direction of the local flow, relative to the Mach wave, is called the Mach angle. The infinitesimal disturbance created at each point along the flight path is propagated along the surface of a cone (the forward Mach cone) whose semi-apex angle is equal to the complement of the Mach angle. The pulse waves, emitted by a point source, are propagated with sonic velocity relative to the undisturbed flow ahead of the source, because, owing to its size, the induced velocity due to the motion of the source is zero. With a body of finite size the velocity of the pulse waves is still sonic relative to the flow around the body, but because of the finite induced velocity due to the body motion, the velocity and angle of forward propagation, relative to the undisturbed flow are increased and decreased respectively. (*See* Fig. 3.)

The induced flow over the body cannot, however, be generated by Mach waves alone, since sudden finite changes in flow direction and finite pressure increases are called for. Consequently, ahead or springing from the body, are found bow and tail waves of finite amplitude called shock waves. Just as Mach waves may be regarded as envelopes of pulse waves, so shock waves may loosely be regarded as envelopes of compression Mach waves. Shock waves propagate normal to themselves with supersonic speed relative to the undisturbed flow. The bow and tail shock waves around a two-dimensional body will be straight only when the velocity of the body is uniform in a straight line, the flow behind the shock is supersonic relative to the body, and when no expansion waves (such as the fan of waves *POQ* in Fig. 3) interact with the shock waves. When there is interaction the expansion waves reduce the strength of the shock wave and its velocity of propagation. The shock wave is, crudely, the mechanism by which undisturbed air ahead of a body, moving at supersonic speeds, is rapidly accelerated in the direction of motion of the body, in order that smooth flow may occur over the body. The thickness of a shock wave in air is very small and for many practical purposes it may be assumed to be zero.

For a complex body such as an aeroplane, shock waves will be generated at the leading and trailing edges of the wings and tail surfaces and at the nose and tail of the body. Additional shock waves will, in general, also be present around intakes, fairings and so on. Since the main problem under consideration is that of the noise received by a ground observer from a body moving at supersonic speeds not too close to the ground, it is the shock wave configuration in the distant field which is of direct interest and not that corresponding to the vicinity of the aircraft. Simple reasoning will show that, in general, at distances from the aircraft, large compared with its dimensions, the complex shock pattern will be mainly determined by the stronger shocks, especially if they are partly plane. Thus, for an aircraft, the shock pattern will be represented approximately by two main shocks, although at any finite distance from the aircraft it cannot be assumed that the remaining shocks have coalesced with the main shocks, and that their local strength is less than that of the main shocks. Fig. 4 shows the interaction of shock waves from tandem aerofoils. For simplicity, it is legitimate in the approximate treatment which follows to consider

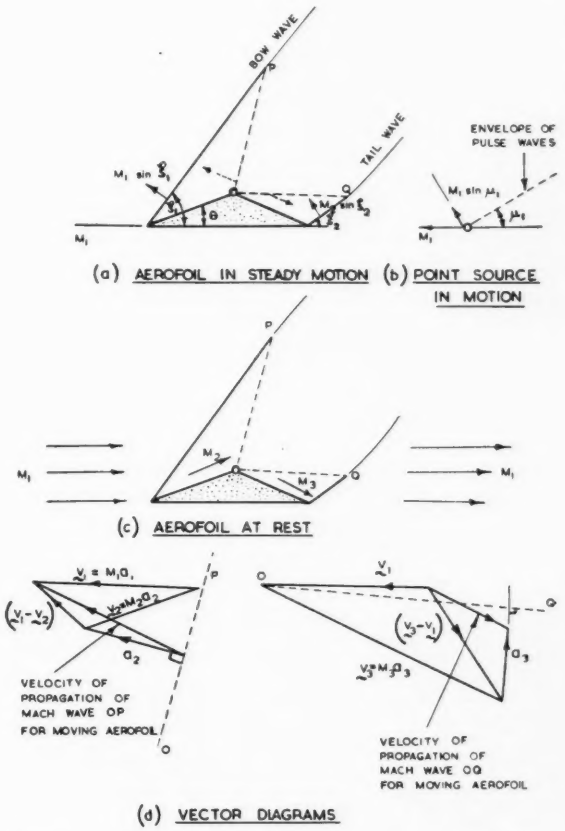

BOW WAVE
TAIL WAVE
ENVELOPE OF PULSE WAVES
(a) AEROFOIL IN STEADY MOTION
(b) POINT SOURCE IN MOTION
(c) AEROFOIL AT REST
VELOCITY OF PROPAGATION OF MACH WAVE OP FOR MOVING AEROFOIL
VELOCITY OF PROPAGATION OF MACH WAVE OQ FOR MOVING AEROFOIL
(d) VECTOR DIAGRAMS

FIGURE 3. Diagram showing the propagation of shock waves and Mach waves for a two-dimensional aerofoil in steady motion.

only the shock waves that develop around a two-dimensional aerofoil or an axi-symmetric body of revolution.

To determine the noise produced by shock waves in motion, it is necessary first to calculate the pressure rise across them at a large distance from the body. This involves assessing the amount by which shock waves decay with distance. The processes of decay are

(*a*) by the action of viscous and thermal effects,

(*b*) by the interaction of expansion and shock waves,

(*c*) by the spreading of free spherical shock waves away from their source.

Figure 5(*a*) shows how the expansion waves interact with the shock waves and gradually reduce their strength to zero at an infinite distance from the aerofoil. The typical pressure signature is shown in Fig. 5(*b*), and is representative of that obtained by calculation, both for aerofoils and bodies of revolution in uniform straight line motion.

If an aircraft or projectile flies past a ground observer at constant supersonic speed, the observer can hear nothing until the bow wave reaches him. The saw tooth (*N*-wave) form of the pressure disturbance due to the bow and tail waves will be observed as one or two cracks or booms depending on the body length, speed, altitude and the ground terrain. When small projectiles are fired at low altitudes the time interval between the bow wave, the tail wave and the ground reflection waves (*see* Fig. 6) will be less than 0·01 seconds and hence two or more discrete sounds cannot be detected by the ears.

5.2. JET, WAKE AND BOUNDARY LAYER NOISE

The noise emission from jets, wakes and boundary layers will have a similar character to that created at subsonic body speeds. One main difference is that sound waves propagated out from a jet or wake cannot penetrate into the region between the bow and tail waves, apart from the small percentage of the total output which is transmitted forward through the subsonic part of the boundary layer. Hence disturbances, giving rise to noise, will exist in the region between the bow and tail waves, although the main noise, apart from that due to the moving shock waves, will exist to the rear of the tail wave. A common example of the wake noise, following that due to shock waves, is that from a shell or bullet. This gives rise to the prolonged hissing noise, the pitch of which decreases on passing, as a result of Doppler effect.

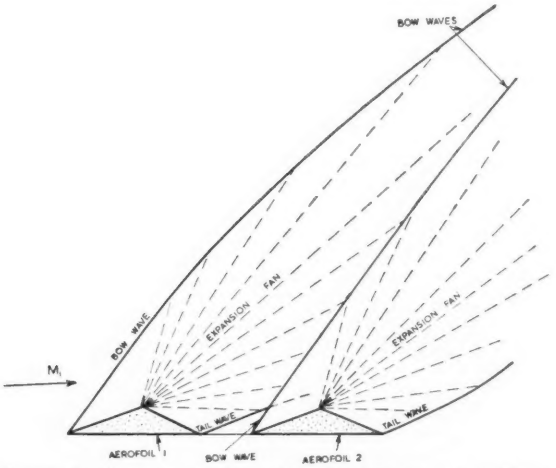
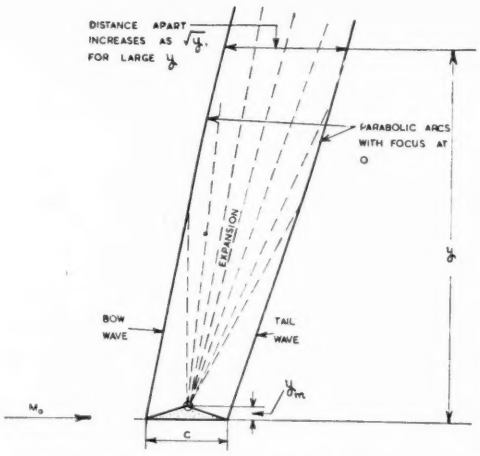
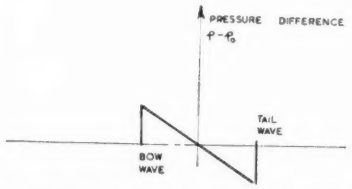


FIGURE 4. Approximate formation of shock waves around two adjacent aerofoils.



(a) SHOCK WAVE AROUND A WEDGE SHAPED AEROFOIL AT STEADY SUPERSONIC SPEEDS.



(b) PRESSURE SIGNATURE OF SHOCK WAVES AT A LARGE DISTANCE FROM A TWO-DIMENSIONAL AEROFOIL MOVING AT STEADY SUPERSONIC SPEEDS

FIGURE 5. Diagram showing the formation of shock waves around an aerofoil in steady motion.

5.3. GENERAL CONCLUSIONS

It has been shown qualitatively how the noise from bodies moving at subsonic speeds differs from that at supersonic speeds. The main difference lies in the discontinuities in pressure associated with the formation of shock waves around the body. The remarks relating to the ear response show that in general two shock waves cannot be heard separately unless their time interval is greater than 0·01 seconds.

One important conclusion is, that in order to calculate the noise intensity from aircraft travelling at supersonic speeds the shock wave pattern around the aircraft must be known. This is known reasonably well, apart from certain minor gaps, for bodies travelling at uniform speeds, but the development of shock waves in accelerated and retarded flight has so far received little attention.

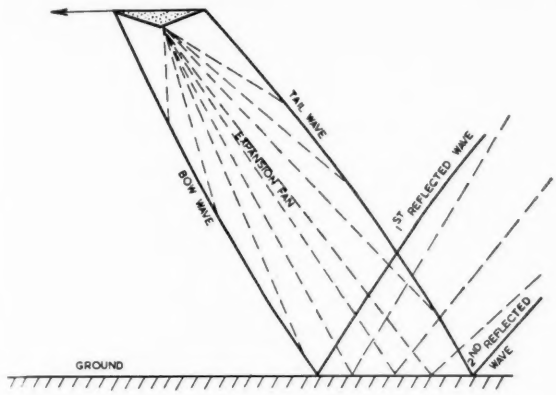


FIGURE 6. Diagram showing the formation of reflected shock waves from a supersonic aerofoil travelling parallel to the ground.

6. Mach Wave Patterns Formed by a Moving Source

Before considering the changes that occur in the shock pattern around a body when it is accelerated or retarded, the corresponding changes in the Mach wave pattern formed by a moving source are discussed. In (*i*) the physics of some simple illustrative patterns are considered, in (*ii*) the theory is outlined.

(*i*) *Examples of some simple patterns*

It is assumed that the source moves through a uniform fluid which is initially at rest, and that the spherical pulse waves, emitted by the source during its motion, travel through the fluid with constant sonic speed. Figs. 1 and 2 show part of the complete set of waves at a given time instant. At subsonic speeds the crowding together of the pulse waves ahead of the source is clearly seen, whereas at steady supersonic speed the conical envelope at the forward part of the pulse waves is visible. Figs. 7, 8, 9, 10 and 11 show that in unsteady supersonic motion the envelopes form Mach waves of concave and convex curvature divided by cusps[11], [12]. Obviously a property of the Mach wave is that it moves everywhere normal to itself at the speed of sound. Hence a Mach wave, whose curvature is concave to the direction of motion, will focus at a point ahead, which must be its centre of curvature. Beyond this point, however, the Mach wave becomes a wave whose curvature is convex to the direction of motion. This helps to explain why a cusp and a rear wave of convex curvature are formed when a source accelerates in a straight line through the speed of sound (*see* Fig. 7). Thus the Mach waves formed by the accelerated source generate a closed loop in any longitudinal plane passing through the axis. When the source is now retarded to subsonic speeds the Mach waves become convex forwards and tend to move ahead of the source (*see* Fig. 8) since their speed of propagation is greater than that of the source. Both the front and rear waves of the closed loop then eventually move ahead of the source. The distance apart of the waves, of the loop, along the axis (straight line motion) remains constant but the height of the loop increases. The cone angle of the loop at a large distance from the position at which the highest Mach number $M_{\max}$ of the source is reached, is equal to

$$2\left(90^\circ - \sin^{-1}\left(\frac{1}{M_{\max}}\right)\right).$$

When a source is accelerated after steady motion at a supersonic speed has been attained, two cusps are formed in the forward Mach wave (*see* Fig. 9). The inner cusp is generated along the forward Mach cone, corresponding to the initial Mach number, with its apex at the point of initial acceleration. The outer cusp spreads outwards. Its path depends upon the history of the accelerated motion.

(*ii*) *The equation of the wave envelope for an arbitrarily moving source*

Although the complete wave envelope may be geometrically constructed using the principle of expanding

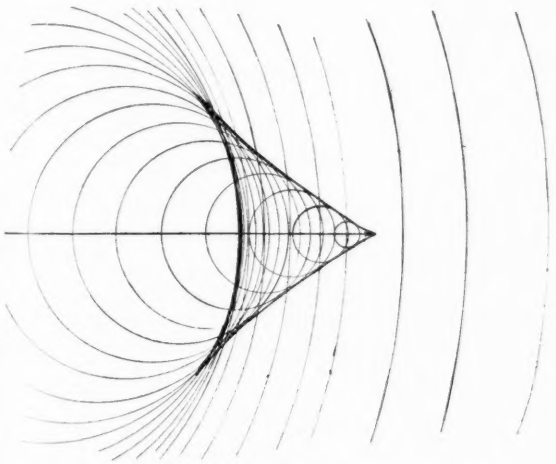


FIGURE 7. Source accelerating along a straight line from subsonic to supersonic speed.

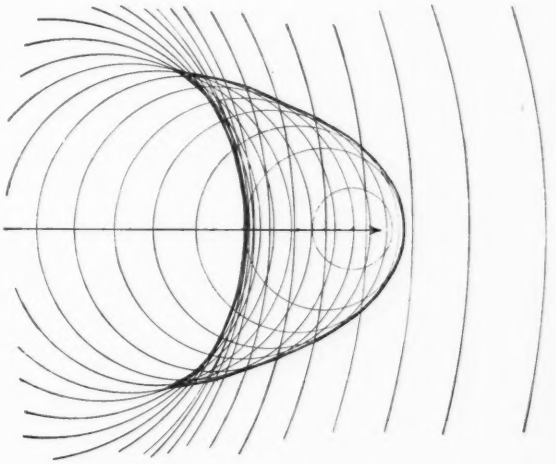


FIGURE 8. Source accelerating along a straight line from subsonic to supersonic and then retarding to subsonic speed.

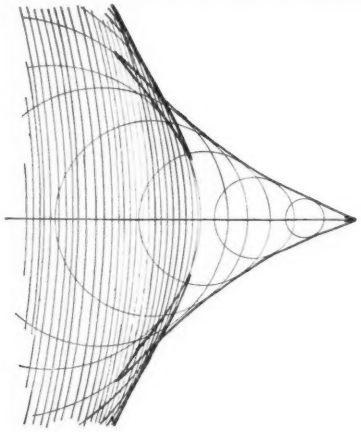


FIGURE 10. Source moving in a circle at steady supersonic speed.

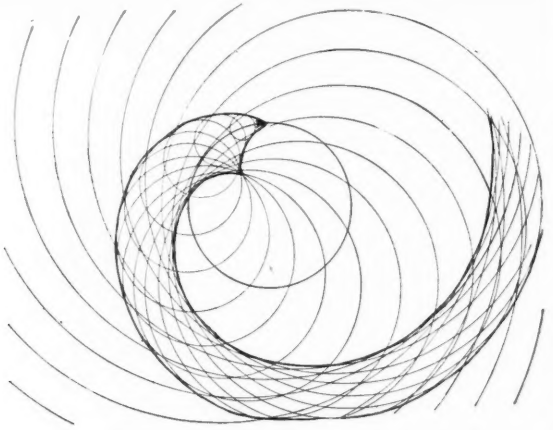


FIGURE 9. Source accelerating along a straight line after steady supersonic motion.

spherical waves, the drawback to this method is that it becomes rather indeterminate in the region of the cusp points unless an excessively large number of circles is drawn. To overcome the difficulty of locating cusps, two simple expressions will be introduced to locate the wave envelope and the cusp lines.

Consider a source which has moved along the line BA (Fig. 13) and has reached the point A at the present time $t=0$. Spherical pulse waves will have been emitted along its path at each past instant. These waves will be expanding outwards away from their points of formation with the speed of sound a. The whole system of pulse waves will be viewed at the present time. Consider the spherical wave which was emitted at the time $t=-\tau$ as the source passed through the point C whose Cartesian co-ordinates are (ξ, η, ζ). Let a point D, on the sphere, have co-ordinates (x, y, z).

The equation of the sphere is

$$R^2=(x-\xi)^2+(y-\eta)^2+(z-\zeta)^2$$

where $R=a\tau$,

or
$$a^2\tau^2-(x-\xi)^2-(y-\eta)^2-(z-\zeta)^2=0 \quad . \qquad (1)$$

The whole of the inner Mach line reaches O at the same instant provided that $r=r_0\exp\left[\dfrac{-\theta}{\sqrt{(M^2-1)}}\right]$

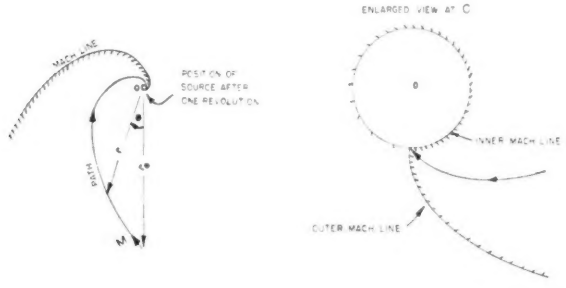


FIGURE 11. Source moving along the path of an equiangular spiral at steady supersonic speed. $M=\sqrt{2}$.

Differentiating equation (1) with respect to τ, keeping x, y, z constant, gives

$$a^2\tau+(x-\xi)\dot{\xi}+(y-\eta)\dot{\eta}+(z-\zeta)\dot{\zeta}=0 \quad . \qquad (2)$$

and differentiating again with respect to τ,

$$a^2+(x-\xi)\ddot{\xi}+(y-\eta)\ddot{\eta}+(z-\zeta)\ddot{\zeta}-\dot{\xi}^2-\dot{\eta}^2-\dot{\zeta}^2=0 \quad . \qquad (3)$$

where $\dot{\xi}=d\xi/d\tau$ and so on. Let the velocity of the source at the point (ξ, η, ζ) be V, having the direction cosines (l, m, n). Therefore

$$\left.\begin{aligned}\dot{\xi}&=-Vl\\ \dot{\eta}&=-Vm\\ \dot{\zeta}&=-Vn\end{aligned}\right\} \quad . \quad . \quad . \qquad (4)$$

and
$$\dot{\xi}^2+\dot{\eta}^2+\dot{\zeta}^2=V^2. \quad . \quad . \qquad (5)$$

since $\dot{\xi}=d\xi/d\tau=-d\xi/dt$ and so on. Thus equations (1), (2) and (3) become

$$a^2\tau^2-(x-\xi)^2-(y-\eta)^2-(z-\zeta)^2=0 \quad . \qquad (6)$$

$$aR\left[1-\frac{V}{a}\left\{l\frac{(x-\xi)}{R}+m\frac{(y-\eta)}{R}+n\frac{(z-\zeta)}{R}\right\}\right]=0. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

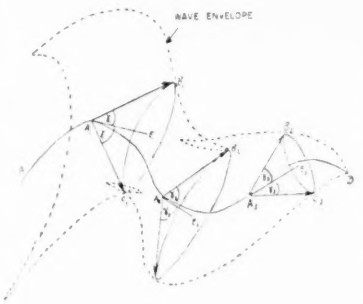
$$R\left[\frac{a^2-V^2}{R}+\left\{\frac{\ddot{\xi}(x-\xi)}{R}+\frac{\ddot{\eta}(y-\eta)}{R}+\frac{\ddot{\zeta}(z-\zeta)}{R}\right\}\right]=0. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

A point (x, y, z) which satisfies equation (6) will lie on the spherical pulse wave. If it also satisfies equation (7), then the point will lie on the wave envelope. The third expression (8) is the condition that the wave envelope forms a cusp. Thus if the point D satisfies (6) it lies on the spherical wave, if it satisfies (6) and (7) it lies on the wave envelope and if it satisfies (6), (7) and (8) then it lies at a cusp point on the envelope.

Let γ equal the angle the tangent to the source path at the point (ξ, η, ζ) makes with the radius vector R, drawn to the point where the spherical wave touches the envelope. Then γ is the complement of the Mach angle, and from (7),

$$\frac{a}{V}=\cos\gamma$$

or
$$\gamma=\cos^{-1}\frac{1}{M} \quad . \quad . \quad . \qquad (9)$$



AD is the flight path
D is the present position of the source.
τ_1 etc. is the time taken for the source to travel the distance A_1D_1
The cone $A_1B_1C_1$ has its axis A_1E_1 along the flight path at A_1 and its semi-vertex angle is $\gamma = \frac{1}{2}\pi -$ Mach angle at A_1.
The length $A_1B_1 = A_1C_1 = \tau_1 a$, where a is the constant speed of sound.

FIGURE 12. Construction of wave envelope for arbitrary motion.

where M is the instantaneous Mach number at the point C. Thus, as the source passes through the point (ξ, η, ζ) a circular element of the wave envelope is emitted. This circular element will travel away from the point of emission with the speed of sound, and will trace out a cone of semi-vertex angle $\cos^{-1}(1/M)$, and whose axis is the direction of motion of the source as it passed through the point (ξ, η, ζ).

Let the magnitude of the acceleration of the source at (ξ, η, ζ) equal $f = \sqrt{(\ddot{\xi}^2 + \ddot{\eta}^2 + \ddot{\zeta}^2)}$. Then if the radius vector from (ξ, η, ζ) to the wave envelope makes an angle α with the direction of acceleration, condition (8) reduces to

$$R\left(\frac{a^2 - V^2}{R} + f\cos\alpha\right) = 0$$

or

$$R = \frac{a^2(M^2-1)}{f\cos\alpha} \quad . \quad . \quad . \quad (10)$$

For motion in a straight line equation (10) can be written

$$R = \frac{a(M^2-1)M}{\dot{M}} \quad . \quad . \quad . \quad (11)$$

where

$$\dot{M} = \frac{1}{a}\frac{dV}{dt}.$$

A cusp will form on the envelope when condition (10) is satisfied. If $f\cos\alpha$ is positive when the source passes through the point (ξ, η, ζ) then a cusp is formed after an interval of time

$$\frac{a(M^2-1)}{f\cos\alpha} \quad . \quad . \quad . \quad (12)$$

The complete wave envelope is formed by constructing all the circular elements corresponding to each point on the path for which the motion was supersonic. The envelope will consist of concave and convex sheets which are separated by cusp lines.

The formation of cusp points may perhaps be more easily understood by considering the curvature of a wave element at its instant of formation. The element will be initially concave outwards with radius of curvature

$$\frac{a^2(M^2-1)}{f\cos\alpha}$$

That is, the element will come to a focus at its centre of curvature, and then diverge in the form of a convex element. Fig. 14 illustrates the formation of a cusp from a concave wave envelope, EF. The wave envelope which is formed at some later instant may be constructed by producing all the normals to the wave front for a constant distance such that $B_1C_1 = B_2C_2 = B_3C_3 = GG_1 = EE_1$. It will be seen that the envelope between F_1 and G_1 is still concave since none of the normals intersect, the wave element at G is focused at its centre of curvature G_1 and the remaining part of the envelope G_1E_1 is convex.

Figure 12 illustrates the method of constructing the wave envelope for the arbitrary motion of a source without resorting to spherical pulse waves. Let the instantaneous forward Mach cones, having the semi-apex angles $\gamma_1, \gamma_2, \gamma_3$ ..., be drawn from the corresponding points A_1, A_2, A_3 ... on the flight path. The slant side of each cone A_1B_1, A_2B_2, A_3B_3 ... will be of length $a\tau_1$, $a\tau_2$, $a\tau_3$ ... where τ_1, τ_2, τ_3 ... are the times taken for the source to travel from A_1, A_2, A_3 ... respectively to its present position D. The surface drawn touching the base circles of all cones will give the instantaneous Mach wave when the source is at D. The cusps can be located by determining which points satisfy the relation

$$\tau = \frac{a(M^2-1)}{f\cos\alpha}.$$

Figures 15 and 16 show a three-dimensional sectional model of the wave envelope formed by a source moving in a circle at a constant Mach number of 2. (*See* Fig. 10.)

If, in the motion illustrated in Figs. 10, 15 and 16, ρ is the radius of curvature in the circular path, the radius of the pulse wave at the cusp in the plane of the motion is, by equation (10),

$$R = \rho\cos\mu \quad . \quad . \quad . \quad (13)$$

and the radius of the circle generated by the cusp is ρ/M.

Similarly in the motion illustrated in Fig. 11, if the equation of the equiangular spiral in polar co-ordinates is

$$r = r_0 \exp\left(-\frac{\theta}{\sqrt{(M^2-1)}}\right) \quad . \quad . \quad (14)$$

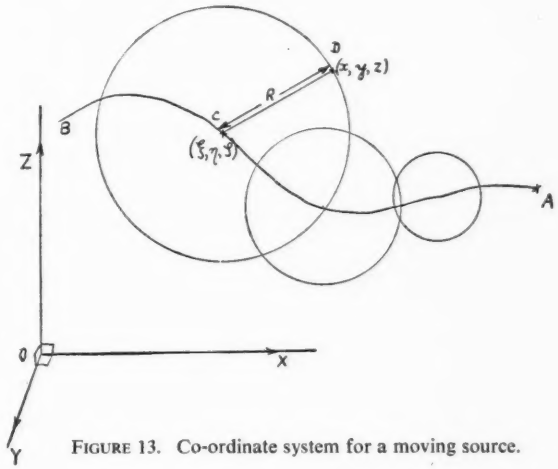


FIGURE 13. Co-ordinate system for a moving source.

where M is constant, the radius of the pulse waves at the cusp in the plane of motion is

$$R=r. \quad . \quad . \quad . \quad . \quad (15)$$

Hence, the cusp is stationary with respect to the moving source, since the source reaches the centre or origin at the same time as the inner wave. If the source completes only one revolution the internal Mach line traces out a circle.

7. The Shock Wave Formation Around Isolated Two-dimensional and Axi-symmetric Bodies of Revolution

In this section the changes that occur in the system of shock waves around a body in steady, accelerated or retarded flight are discussed and compared.

7.1. STEADY MOTION

Observations of the flow around bodies at steady high subsonic speeds above the critical Mach number show that a small nearly normal shock wave is formed near the surface downstream of the sonic point. With increase in Mach number this shock wave spreads to a greater distance from the surface and at the same time moves back towards the trailing edge. The wave is then of finite length, since the region of supersonic flow relative to the body is finite also. The shape of the tail wave is in general either bifurcated, with its rear member nearly normal to the surface or wake, or it is nearly normal to the surface itself. The exact shape depends upon the free stream Mach number, the shape of the body, and the interaction with the boundary layer[13], [22]. The extent of the tail waves increases as the steady body speed tends to a Mach number of unity.

At steady supersonic speeds a bow wave is formed ahead of the body. It becomes attached to the nose of the body, if its nose is sharp, above a certain Mach number, which is a function of the nose angle. Between the bow and tail waves there exist expansion waves which are formed either continuously over the surface of a curved body or in the form of a fan of waves at the shoulders of a straight sided body (*see* Fig. 5). The expansion waves are the means by which the flow, relative to the body, is accelerated between the bow and tail waves. The interaction of the expansion waves with the bow and tail waves reduces the strength of the tail

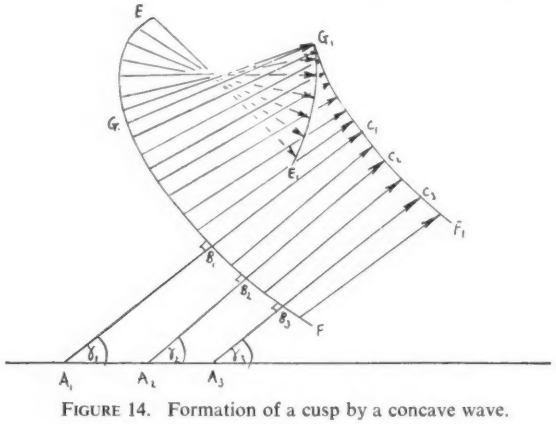


FIGURE 14. Formation of a cusp by a concave wave.

waves at a distance from the body. It has been shown by Lighthill[14] and others[15], [16] that the shock wave pattern around two-dimensional aerofoils in steady motion at supersonic speeds can be represented by parabolae at large distances.

As the Mach number is reduced the process is reversed, the bow wave becomes detached at a Mach number depending on the nose angle. The distance between the bow wave and the nose increases as the Mach number approaches unity from above and when the Mach number equals unity the separation distance is infinite.

The pressure change across the bow wave of a two-dimensional aerofoil at large distances is[15] (*see* Fig. 5)

$$\frac{\Delta p}{p_0}=\frac{2\gamma}{\sqrt{(\gamma+1)}}\sqrt{\left(\frac{y_m}{y}\right)}\left[1+\frac{3M_0^2-4}{4(M_0^2-1)}\sqrt{\left\{\frac{(\gamma+1)y_m}{y}\right\}}\ldots\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

where M_0 is the Mach number of the aerofoil, $2y_m$ is its maximum thickness and y is the distance normal to the aerofoil. The pressure falls between the bow and tail shock waves and increases across the tail wave by a value similar to that given in equation (16).

The distance apart of the shock waves at distance y from the aerofoil chord c is

$$d=\frac{cM_0^2}{(M_0^2-1)}\sqrt{\left\{(\gamma+1)\frac{y_m}{c}\frac{y}{c}\right\}}+\ldots \quad . \quad (17)$$

The corresponding calculations by Whitham[17], [18], for a parabolic shaped body of revolution of fineness ratio δ and length l, show that across the bow wave

$$\frac{\Delta p}{p_0}\simeq 0{\cdot}53(M_0^2-1)^{\frac{1}{4}}\frac{\delta}{(y/l)^{\frac{1}{2}}} \quad . \quad . \quad (18)$$

and a similar result holds for the tail wave. The distance apart of the shock waves is

$$\frac{d}{l}\simeq 1{\cdot}82\frac{M_0^2\delta(y/l)^{\frac{1}{2}}}{(M_0^2-1)^{\frac{1}{4}}} \quad . \quad . \quad (19)$$

These formulae all apply to the case of zero body incidence and where the shock waves close to the body are not too strong. The effect of incidence is roughly to increase the strength of part of the shock front by an amount similar to that obtained with a body of increased thickness.

No attempt has been made to present formulae for the pressure changes across shock waves in subsonic flow. It is known that the strength of these waves is not negligible and it will be shown next that they play a very important part in determining the shock formation in accelerated flight through the speed of sound.

7.2. ACCELERATED AND RETARDED MOTION

When a body* is uniformly accelerated up to high subsonic speeds, below the critical Mach number, the flow pattern around the body at any instant will not be markedly different from that at the corresponding steady speed. The critical Mach number will, however, be a function of the acceleration, but its change from the steady value may not be significant. At flight speeds above the critical the body shock wave begins to develop

*In what follows the words body and aerofoil will be used to describe the same moving object.

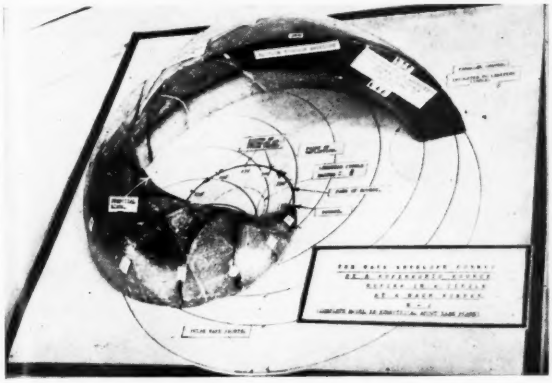


FIGURE 15. Sectional model of the wave envelope formed by a source moving in a circle at constant speed. $M=2$.

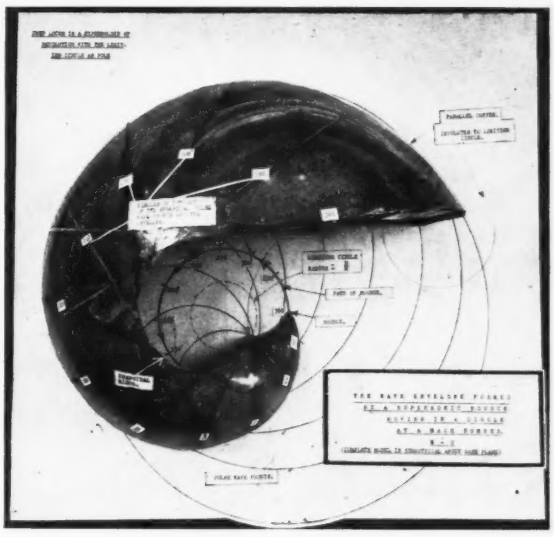


FIGURE 16 (*right*). Sectional model of the wave envelope formed by a source moving in a circle at constant speed. $M=2$.

but, since it cannot be formed instantaneously, its form and position will be a little different from that at the corresponding steady speed. Consider the growth of this shock wave when an aerofoil is accelerated slowly through the critical Mach number. Just after the local speed of the flow relative to the aerofoil, outside the boundary layer, reaches sonic speed, a region of supersonic flow develops of finite extent. At its forward end, the expansion waves accelerate the flow, whereas, near its rearward end the compression waves, which retard the flow, coalesce and form a weak shock wave approximately normal to the aerofoil surface. As the speed increases so the region of supersonic flow expands and the normal shock, which is increasing in height, moves backwards approximately normal to itself. If boundary conditions are favourable, for instance if boundary layer separation occurs, the disturbances generated by the separation will coalesce to form a second shock wave in front of the first. The formation of the two shock waves will probably be similar to the formation of Mach waves around an accelerated source (*see* Fig. 7). The result will be a bifurcated wave, whose rear member is the original normal shock. It can easily be shown that the strength of the rear member will be less than the front member of the tail wave.

When the subsonic speed is sufficiently high the shock formation will reach the trailing edge (*see* Fig. 17). Since the acceleration has been assumed small, the shock wave pattern at each speed should quickly develop to its corresponding steady-state configuration. It can therefore be assumed that, since the steady-state shock configuration is fairly well known, so the accelerated shock pattern will also be known at high subsonic speeds. Thus so far no new ideas need be introduced in considering the modification to the shock pattern due to an acceleration in the subsonic regime.

This is not the case in considering the effect of a retardation back to a subsonic speed below the critical. The tail shock waves will move slowly forward towards the nose and *will not vanish as soon as the body speed drops below the critical Mach number**. The shock waves will tend to coalesce into a single wave which moves ahead of the nose. The distance of separation will be a function of the future history of the body. The wave, or waves, will be weak and will be propagated with the speed of sound. They must, however, represent pressure waves of large amplitude and would be heard by an observer, together with the remainder of the noise emitted by the body. Since these waves are of finite length and are approximately normal to the flight path when they leave the aerofoil, their effect, relative to the ground, will be very localised.

When the acceleration of the aerofoil is continued so that its speed just reaches the speed of sound, a bow wave is formed, which, unlike the tail wave, remains approximately normal to the flight path, near the body, at least over a finite range of supersonic speeds. The bow wave begins to form ahead of the body and its distance from the body is a function of the acceleration, the time history of the motion, and the body geometry.

At steady sonic speed the bow wave will be at an infinite distance ahead of the nose, but in this case the motion is implicitly assumed to have been going on for an infinite time previously. For all practical flight cases, therefore, the bow wave must be expected to be at a finite distance from the nose. The bow wave is not formed instantaneously. Thus for a body initially at rest, strictly speaking, the bow wave can only reach its steady state configuration after an infinite time. No

*Experiments in wind tunnels at steady or unsteady speeds will not show these effects. This is because the instantaneous shock formation around the wind tunnel model, during an increase or decrease in speed, is the result of disturbances created at times immediately before the given instant. Thus, disturbances forming shock waves around the model during the time of accelerated flow cannot themselves form shock waves during the time of retarded flow, since by then they will have moved far downstream. When the free stream Mach number falls below the critical the shock waves disappear.

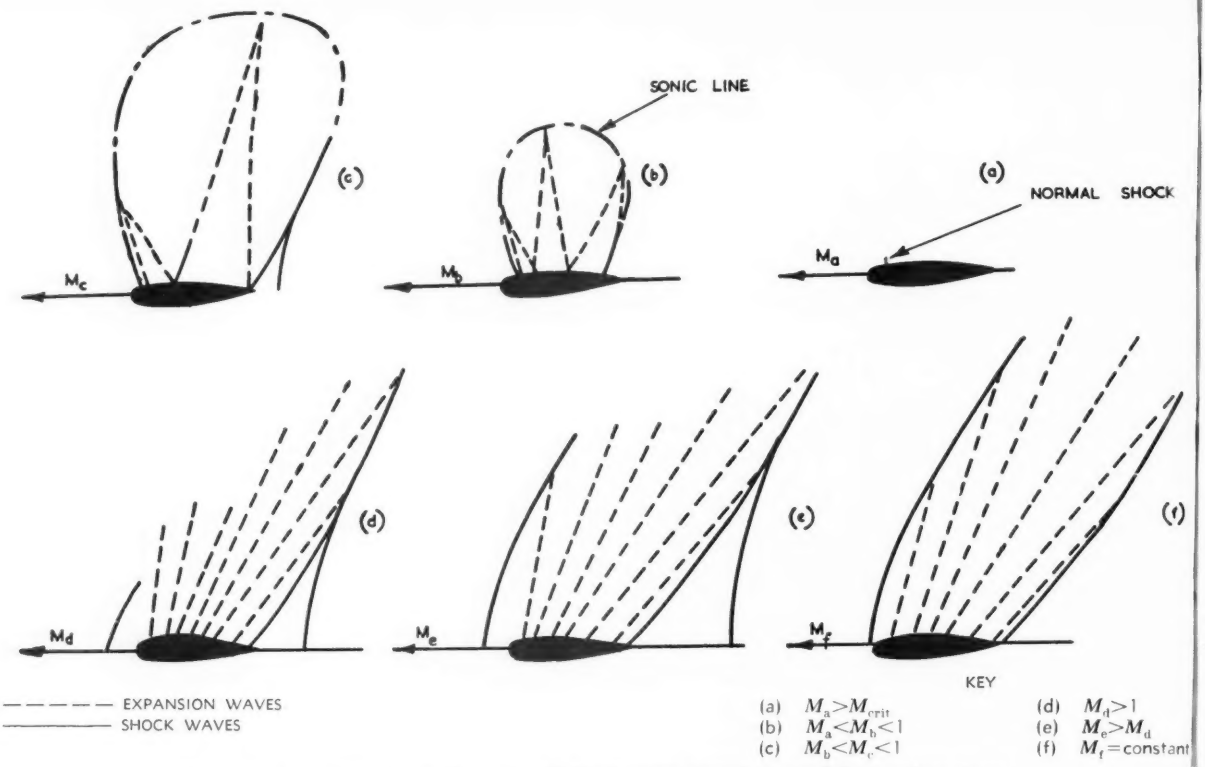


FIGURE 17. The approximate formation of shock waves around an aerofoil at various stages during an acceleration from subsonic to supersonic speeds.

proof has yet been advanced as to whether the bow shock wave, produced by the motion of an accelerated bluff body, occurs when the speed is just sonic or slightly less than sonic. It is known[15] that in one-dimensional flow shock waves occur ahead of bodies at subsonic speeds if they are accelerating. In general as a body accelerates above the speed of sound the bow wave, as already stated, remains approximately normal to the flight path, near the body, and it will become attached to the body at a sufficiently high supersonic Mach number depending on the nose shape. Away from the body axis, the interaction of the expansion fan with the shock wave reduces its inclination relative to the flight path. *It must be emphasised that the field of flow associated with a body of finite size, particularly ahead of it, inhibits the formation of a concave bow wave having a cusp similar to that shown in Fig. 7.* If an acceleration occurs after a body has reached a steady supersonic speed, the cusps which are formed in the picture of Mach waves (*see* Fig. 9) are not reproduced with shock waves. A simple analysis of the flow in the loop behind the front wave will show why shock waves, with expansion waves interacting with them, cannot generate this pattern. The experiments in shallow water, discussed later, show that in all the observed continuous motions so far, the bow wave has remained continuous also.

Consider now what changes occur in the tail wave pattern as the accelerated body exceeds the speed of sound. It has been shown that when the body reaches sonic speed the front member of the tail wave, in general, is inclined backwards, relative to the direction of motion, near the body and becomes more normal at a distance. Also, in general, a rear nearly normal wave exists in the wake of the front member of the tail wave, and is attached to it at its outer extremity. As the speed of the body increases so the distance apart of the two parts of the tail wave increases also, since the front member is attached to the body, and the rear member is moving normal to itself at approximately the speed of sound. *The suggested shock formation for a body accelerated from subsonic to supersonic speeds is a bow wave ahead of or attached to the nose, and separated from the front tail wave by a system of expansion waves, and a rear transverse wave joined to the front tail wave at its outer extremity.* (*See* Fig. 17.)

When the body is retarded (*see* Fig. 18) and its speed falls below the critical Mach number* the bow wave will now be far ahead of the nose since it detaches itself from the body when the speed is a little above sonic†. The front tail wave will move slowly forward towards the nose and in doing so becomes approximately normal to

*It appears that the critical Mach number in steady motion will be different from that in accelerated or retarded motion. In accelerated or retarded motion the instantaneous flow pattern is a function of the previous time history of the body.

†The bow wave will start to move away from the nose of the body at a low supersonic Mach number which is a function of the body shape.

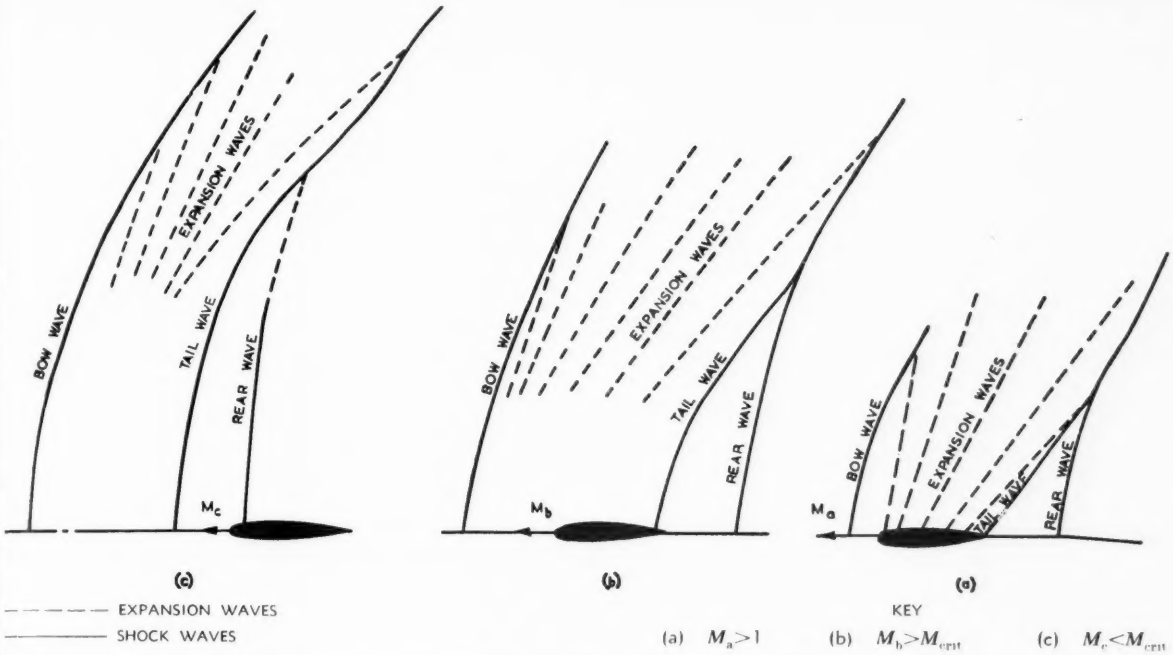


FIGURE 18. The approximate formation of shock waves around an aerofoil at various stages during a retardation from supersonic to subsonic speeds.

the surface. Its shape changes and its curvature becomes convex in the direction of motion. The rear tail wave moves towards the aerofoil, overtakes it and finally, it also moves ahead of the body. *The suggested shock formation ahead of a body, retarded from supersonic motion of finite duration to subsonic, is a bow wave separated from the front tail wave by a system of expansion waves and trailing farther behind a rear transverse wave joined to the front tail wave at its outer extremity.* If these three shock waves were formed around a body whose maximum speed only just exceeded the speed of sound, the waves will all be approximately plane and a simple calculation[15] will then show that the rear tail wave must eventually overtake the front tail wave, while the bow wave must move faster than the front tail wave, because of the expansion waves between them. Thus at a distance from the body either three or two shock waves must be expected. For higher maximum body speeds a similar result is to be expected.

Thus for a simple body or aerofoil the formation of shocks far ahead of the region of accelerated and retarded motion, in which the motion of the body just exceeded the speed of sound, is not unlike the simple Mach patterns for a source executing a similar motion. The distance apart of the "two" waves can be crudely calculated from the time history of the motion and in particular from the positions on the flight path at which sonic speed and the critical Mach number were reached during the acceleration and retardation. A similar answer will be obtained if it is assumed that the distance between the bow and front tail waves, increases[15] according to $\sqrt{t}$ where t is the time after these waves detached themselves from the body. This result will apply only to plane or nearly plane waves and will be approximate only in a range of body speeds close to sonic.

The results of the shallow water experiments discussed in Section 8 support this qualitative argument. However, the possibility cannot be excluded that the arguments will require modification in the light of more detailed experiment and a rigorous analytical treatment.

An experimental investigation of this problem could only be done conveniently by performing a series of free flight tests under fixed conditions of acceleration and retardation. The results obtained from projectiles fired from guns are not suitable, since the bow wave is formed first at the instant the projectile penetrates the gun wave. The bow wave is therefore of greater extent than the tail wave as shown in Figs. 19 and 20[19]. The rear tail wave in Fig. 20 bears a striking resemblance to the rear tail waves obtained behind moving bodies in shallow water.

Very little can be said about the magnitude of pressure across the shock waves far distant from the accelerated and retarded body. For straight flight paths the pressure change is probably not very different from that calculated, at a similar distance, for a body moving at a steady speed corresponding to the maximum speed during the manoeuvre. Alternatively, it can be assumed that the pressure excess is inversely proportional to the distance from the source or origin of the shock wave. This result is correct for the expansion outwards of a weak spherical shock wave when interaction with expansion waves is neglected. For curved flight paths the approximate theory of Warren[1] could be used.

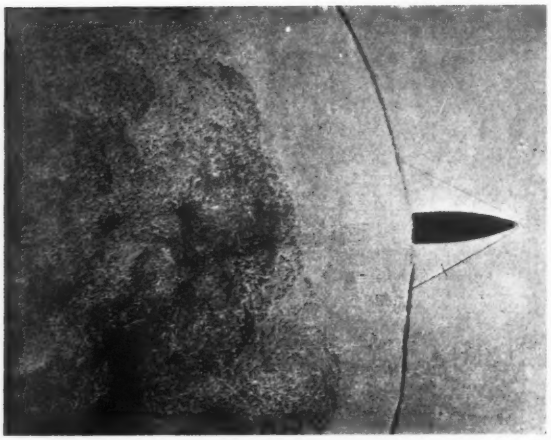


FIGURE 19. The beginning of the bow wave from a pointed bullet [19].

8. Experiments in a Hydraulic Analogy Channel

A series of simple experiments have been performed on bodies moving in shallow water, to establish the shock pattern around bodies in accelerated and retarded motion. It is well known [20] that the surface gravity waves propagated by moving bodies in shallow water are analogous to the infinitesimal disturbances caused by the same two-dimensional body moving through a compressible gas. In water the wave velocity is a function of the wave length, but if a depth of $h = 0{\cdot}25$ in. is chosen [21] for ordinary tap water, the wave velocity c will be independent of the wavelength λ except for the small capillary waves. Thus, when $h/\lambda \ll 1$,

$$c = \sqrt{(gh)} \quad . \quad . \quad . \quad (20)$$

It has been shown that the analogy applies only to a perfect gas whose ratio of specific heats $\gamma = 2$. The analogy is not exact between shock waves propagated in a gas and bores or hydraulic jumps* formed in water [21]. However, if the analogy is restricted to values of $M < 1{\cdot}5$ the differences can be neglected. It will be shown in the tests described that large numbers of capillary waves form upstream of the bores. Their presence is unavoidable although their effect on the formation of the bores is almost negligible.

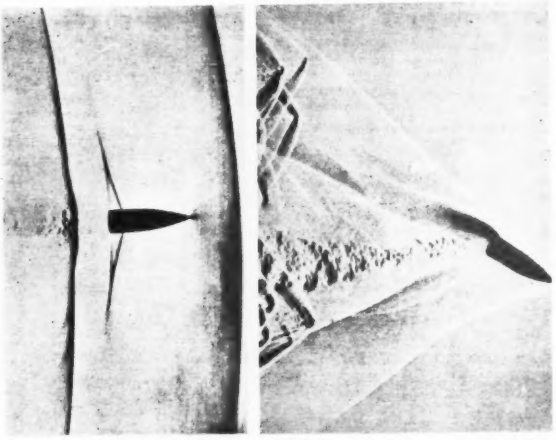


FIGURE 20(*a*) (*left*). The bow and tail waves from a bullet at $M = 1{\cdot}0$ [19].

FIGURE 20(*b*) (*right*). Curved shock waves produced by a bullet which has grazed a wooden board [19].

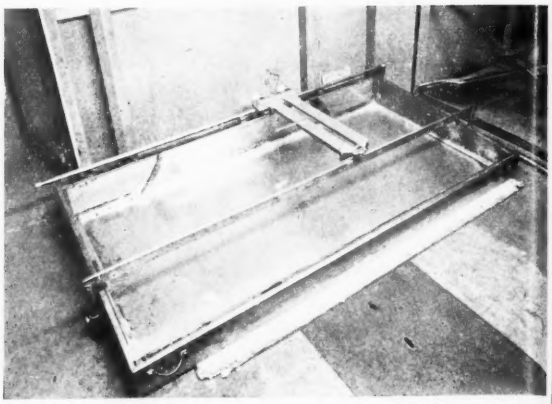


FIGURE 21. Arrangement of hydraulic analogy tank.

Since the strength of the bores, during an acceleration of a body to supercritical speeds† and after a retardation to subcritical speeds, is very small the reproduction of observed formations of bores by photographic methods is extremely difficult. The height of the bore corresponding to a pressure discontinuity of 10 lb./ft.² in air is about 0·001 inches. The apparatus used was not designed for this investigation and great accuracy cannot be claimed for the results obtained.

8.1. APPARATUS

The tests were performed in a tank 5 ft. long by 3 ft. wide having a glass bottom (*see* Fig. 21). The model was attached to a carriage mounted on rails fixed over the tank. The carriage was either moved by hand or its acceleration and deceleration were controlled by springs fixed at one end to earth and to the carriage at the other end. In method (*b*) below, the spark was operated by means of a metal strip, placed on the side of the tank coming in contact with a micro-switch fixed to the carriage. Ordinary tap water was used to a depth of 0·25 in. Photographic records were taken as follows:—

(*a*) The glass bottom was covered on the inside with a flat metal plate. Glancing light was obtained from three 250 watt photo-flood lamps. A 35 mm. camera was held either directly above the model or at an acute angle to the water surface.

(*b*) The metal plate was removed and the water surface was illuminated by a short duration spark placed

*In hydraulics the term *hydraulic jump* is applied only to a stationary discontinuity in the water surface and a moving discontinuity is known as a *bore*.

†In this section, apart from sub-section 8.3, the terms subcritical and supercritical will be used to denote body speeds less than or greater than $\sqrt{(gh)}$.

4 ft. below the tank bottom. The exposures were made direct on Kodak bromide WSG 1.S paper placed 0·25 in. above the water surface. For these tests a grid of wires was suspended below the tank bottom from the moving carriage.

(*c*) The surface of the water was completely covered with aluminium particles to give a strong reflection from the surface. The exposures were taken with a $\frac{1}{4}$ plate camera.

The following models were used

(*i*) 0·5 in. chord and 0·18 in. maximum thickness double wedge section

(*ii*) 3·0 in. chord and 1·0 in. maximum thickness.

The results obtained by use of these three methods (*a*), (*b*) and (*c*) were very similar. Best results were obtained with method (*c*), and for this reason this series alone is discussed in what follows.

8.2. EXPERIMENTAL RESULTS

Method (*c*)

Typical results are shown in Figs. 22 and 23. They show the growth of the bow wave and the front tail wave, as well as the rear tail wave, during an acceleration and retardation from subcritical to supercritical, and back to subcritical speeds. Fig. 24 shows the modified wave pattern when an aerofoil is accelerated to supercritical, retarded to critical, accelerated back to supercritical and finally retarded to subcritical speeds. Fig. 25 shows the wave pattern around tandem aerofoils during an acceleration and retardation from subcritical to supercritical, and back to subcritical speeds. Fig. 26 shows the wave pattern around an aerofoil moving in a circle. Fig. 27 shows diagrammatically the changes in the water level associated with the accelerated motion and should assist in an appreciation of the wave patterns detailed in these photographs.

8.3. DISCUSSION OF RESULTS

Detailed comments on the results are unnecessary since they confirm qualitatively the broad conclusions stated earlier. The main results* are:—

(*a*) Above the critical Mach number the front tail wave is formed and at approximately sonic speed the rear tail wave appears, connected to it at its outer extremity.

(*b*) The rear tail wave is very weak except near its point of attachment to the front tail wave.

(*c*) As the speed increases the rear tail wave moves backwards relative to the aerofoil.

(*d*) When the speed falls below sonic, the bow wave becomes detached and moves off ahead of the nose. The front tail wave changes shape and becomes more normal close to the aerofoil.

*The results will be discussed in terms of the analogous motions of the aerofoils through air. Thus the terms subsonic, critical and supersonic Mach numbers have their usual meanings. Since all the results refer to accelerated and/or retarded motion of an aerofoil the words accelerated and retarded will only be used where it is essential to avoid confusion.

(*e*) The front tail wave moves slowly over the aerofoil surface and detaches itself from the nose when the speed falls below the critical Mach number. It follows in the wake of the bow wave.

(*f*) The rear tail wave overtakes the aerofoil, passes over it, and follows in the wake of the front tail wave. It overtakes the front tail wave in a finite time which depends on the time history of the motion in the high subsonic and supersonic parts of the flight path. There are always one, two or more shock waves ahead of the nose of the aerofoil when it returns to subsonic speeds below the critical.

(*g*) When an aerofoil is accelerated to supersonic, retarded to subsonic, accelerated to supersonic and then retarded to subsonic speeds, the formation of shock waves ahead of the nose depends entirely on the time history of the motion and in particular on the speed reached during the first retardation. Two, three or four

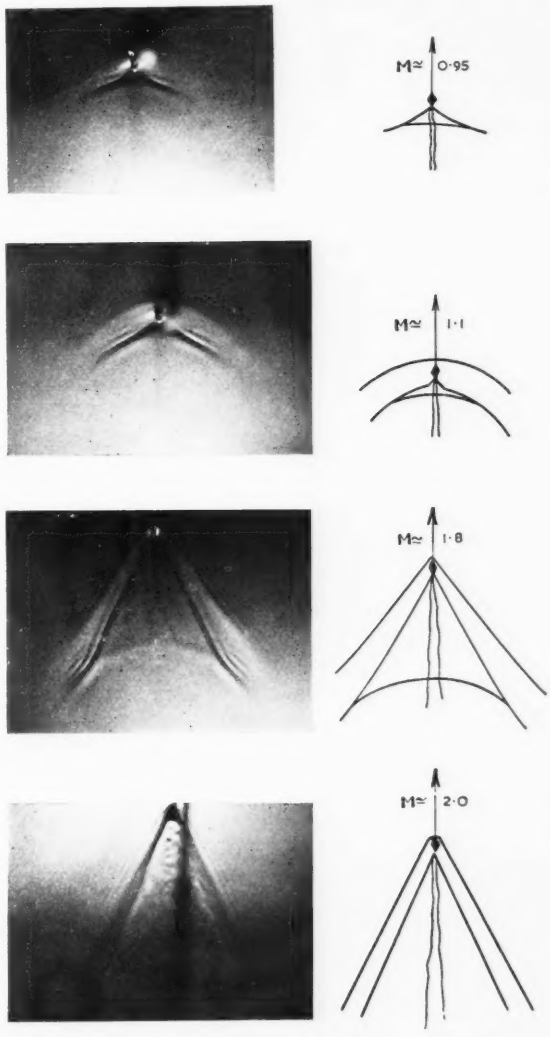


FIGURE 22. Accelerated aerofoil from subcritical to supercritical speeds. (Double wedge aerofoil 0·5 in. chord × 0·18 in. thick.)

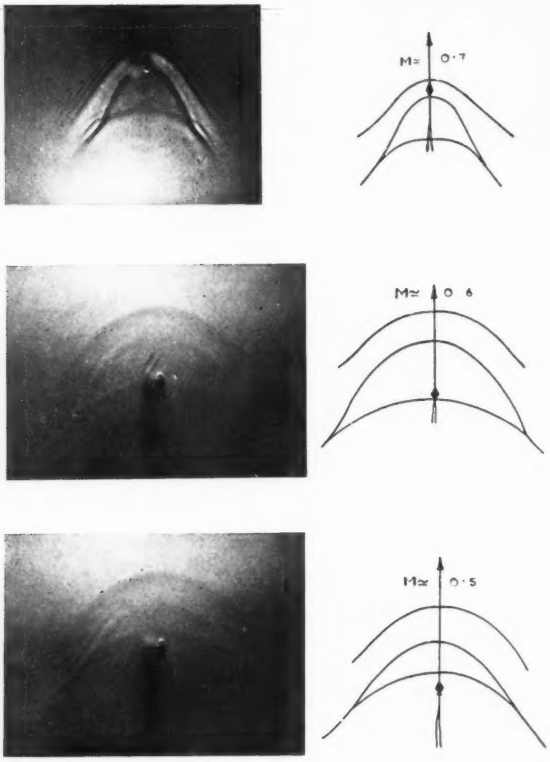


FIGURE 23. Retarded aerofoil from supercritical to subcritical speeds. (Double wedge aerofoil 0·5 in. chord × 0·18 in. thick.)

shock waves will result, although some of the waves will coalesce after a finite time has elapsed.

(*h*) The shock patterns around tandem aerofoils depend on their distance apart and their respective dimensions.

9. Noise Received by Ground Observers when the Time of Supersonic Flight is Finite

9.1. UNIFORM ATMOSPHERE

It has been shown in Section 5 that the noise received by a ground observer from a body travelling at supersonic speeds for a finite time is mainly a function of the shock waves around the body at each instant during the manoeuvre, together with the noise associated with the jet and boundary layers. To see clearly the nature, intensity and duration of the noise, consider a specific

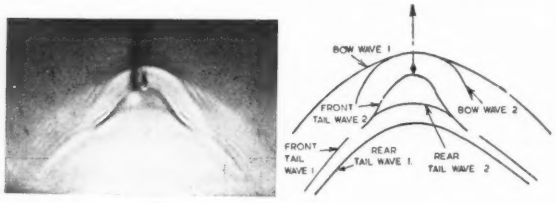


FIGURE 24. Double acceleration and retardation from subcritical to supercritical and back to subcritical speeds.

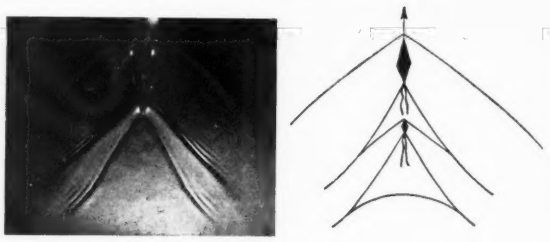


FIGURE 25. Acceleration and retardation of tandem aerofoils.

example. A jet-propelled wing of chord length 30 ft., having a critical Mach number of 0·9, is in a vertical dive. It accelerates through a Mach number of unity at 35,000 ft., attains a maximum Mach number of 1·05 at 30,000 ft., and decelerates through a Mach number of unity at 25,000 ft. The atmosphere is assumed to be uniform throughout and its density and speed of sound are 0·001 slugs/ft.^{3} and 1,000 ft./sec. respectively. This example was considered in Ref. 1 and a similar example was considered in Ref. 2. In the first instance, consider the noise received by an observer positioned on the ground directly below the aircraft. Since the aircraft speed is subsonic, below the critical, from 60,000 ft. down to 36,000 ft. the main noise emitted in this region is from the jet. Assuming that the sound radiators emitting noise upstream of the jet are at rest relative to the aircraft, and that the jet noise is independent of the aircraft speed but is proportional to the square of the distance from the aircraft, a simple calculation shows that the first noise arriving at the ground comes 60 sec. after the aircraft commenced its dive. The noise level is, say, 74·5 decibels or 0·001 lb./ft.^{2} root mean square pressure. The noise level remains approximately constant for a further 140·4 sec. (*see* Fig. 28), during which time the aircraft has reached a height of 37,000 ft. and a Mach number of 0·8.

Between 36,000 ft. and 35,000 ft. shock waves begin to form over the rear of the wing. The noise from the jet that is emitted forwards can no longer escape past the nose of the body and must pile up behind the tail shock wave. This shock wave continues to expand and forms its rear member at about sonic body speed, that is when the aircraft has reached 35,000 ft. The bow wave now forms and increases in dimensions as the aircraft falls a further 10,000 ft. During this same period the rear part of the tail wave falls behind the aircraft and continues to encompass the sound waves produced by the jet between 60,000 ft. and 35,000 ft. which did not escape in front of the aircraft, as well as the noise emitted between 35,000 ft. and 25,000 ft. which was

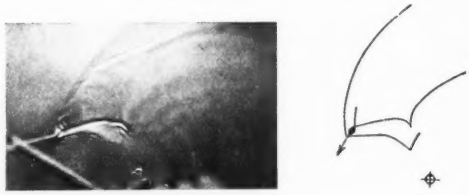


FIGURE 26. Aerofoil moving in a circle.

either propagated in the downstream direction from the region between the two members of the tail wave, or was created in the jet downstream of the rear tail wave. The remainder of the jet noise emitted between 35,000 ft. and 25,000 ft. will be confined to the region between the front and rear members of the tail wave. At 25,000 ft. the bow shock wave separates from the nose of the wing and reaches the ground approximately 200·8 sec. after the commencement of the manoeuvre. Fig. 28 also shows that some of the noise emitted at 36,500 ft. arrives at the same instant, but its intensity is small compared with 2 lb./ft.^{2} which is the estimated increase in pressure across the bow wave near the ground according to Ref. 1. The expansion waves will now meet the ground and will tend to reduce the excess pressure to a suction. In this same period the reflection of the bow wave from the ground, and adjacent buildings, will pass the observer (*i.e.* about 0·01 sec. after the passage of the bow wave). Thus the bow wave and its reflections will give rise to one prolonged crack or boom.

Consider now the path of the front tail wave. It cannot leave the aircraft until the speed has dropped to the critical Mach number of 0·9 which occurs at 19,000 ft. Its rear wave has lagged behind and although it was 230 ft. behind the nose at 25,000 ft. it catches up with the front tail wave at about 20,000 ft. Hence when the tail wave separates from the nose it is 230 ft. behind the bow wave. The tail wave reaches the ground 0·23 sec. after the bow wave and is also heard as a prolonged crack or boom. The increased distance between the bow and tail waves due to the spreading effect of the expansion waves will cause the delay time, between the arrival of the two shock waves at the ground, to increase to about 0·24 sec. The rise in pressure across the tail shock cancels out the suction produced by the expansion waves. The mean pressure aft of the tail wave, neglecting the reflection effects, is approximately ambient atmospheric pressure.

Part of the jet noise created between 25,000 ft. and 35,000 ft., in that order, will be heard immediately afterwards. This will be followed by the remainder of the jet noise created between 25,000 ft. and 35,000 ft. and the "subsonic noise" emitted between 35,000 ft. and 60,000 ft. The jet noise spectrum will be modified by Doppler effect and the jet noise will appear to the observer, first as a high pitched shriek followed by a low pitched roar.

In this example, therefore, two bangs or booms are heard, each of about 0·02 sec. duration, separated by about 0·25 sec.

If in a similar example the Mach number fell to 0·9 at 24,000 ft., instead of 9,000 ft. the front tail wave would leave the aircraft only 50 ft. behind the bow wave and the rear tail wave would still be 180 ft. farther behind the front tail wave. Hence the time interval between the bow and front tail waves striking the ground would be 0·05 sec. and the rear tail wave would follow about 0·20 sec. later. The first and second booms would be of considerably greater amplitude than the third.

Considering typical examples relating to the flight of missiles at low altitudes it can be shown that the time delay between the bow and tail waves may be little

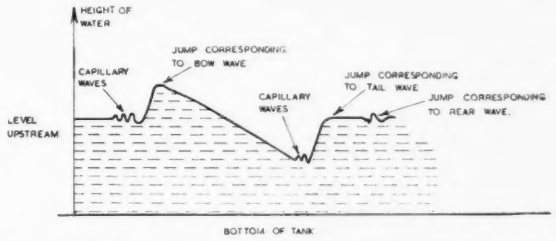


FIGURE 27. The changes in water height associated with the accelerated motion of a two-dimensional aerofoil.

greater than 0·03 sec. and the rear wave arrives about 0·20 sec. later. In this case the time delay between the bow and tail waves, allowing for the effects of reflection, reverberation and the aftersound, is insufficient for two separate booms to be heard. An observer will hear one large boom followed 0·20 sec. later by one weak boom.

This discussion has been concerned with the sequence of the booms and jet noise which is heard by an observer stationed directly under the aircraft. Consider

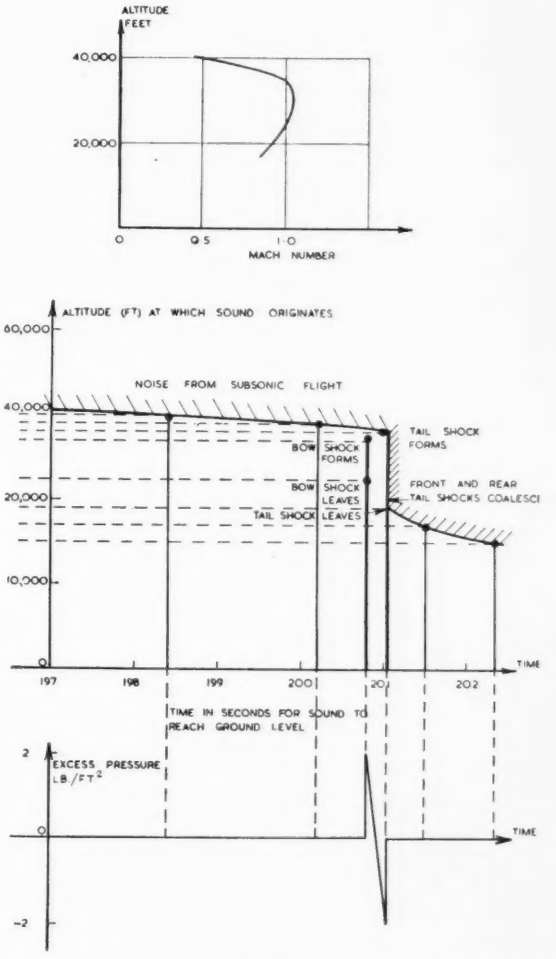


FIGURE 28. The time sequence of pressure disturbances observed at ground level from an aircraft in a high-speed dive.

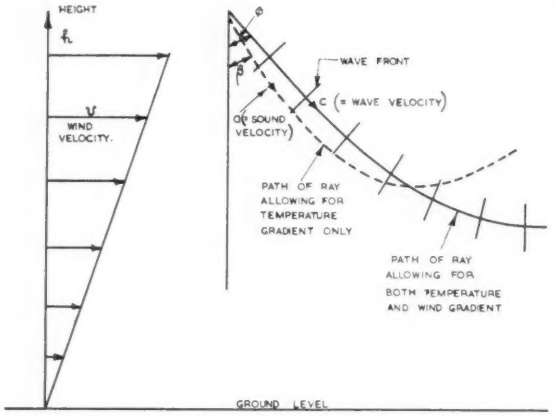


FIGURE 29. The refraction of sound waves due to atmospheric wind and temperature gradients.

now the noise heard by an observer who is in line with the normal to the free stream Mach wave at the position along the flight path at which the aircraft reached its maximum speed. He will hear both the bow and front tail waves only, since the rear tail wave will be either very close to or will have overtaken the front tail wave. Hence either one or two booms will be heard depending on whether the time delay between the two shock waves is less, or greater, than 0·2 sec. approximately. *The sequence and number of booms depends critically on the flight path and the position of the observer.*

When the maximum speed of the aircraft exceeds the Mach number corresponding to attached shock waves at the nose of the body, wings and so on, the simplified picture will not hold. The number of shock waves which are propagated forwards when the aircraft speed falls below the critical Mach number may exceed three. The number depends on the aircraft geometry and the time history of the manoeuvre. To determine whether an observer will hear booms or not, it will probably be sufficiently accurate, for many practical purposes, to construct the complete Mach wave pattern (*see* Fig. 12) at each instant along the flight path and beyond, around a moving point source which replaces the aircraft. In this simplified approach the criterion that an observer will hear a boom, is that the component of the speed of the source along the instantaneous line joining the source to the observer must be sonic[11]*. This criterion clearly does not strictly apply to the body of finite size even though the shock waves far distant from the body are weak.

9.2. NON-UNIFORM ATMOSPHERE

When shock waves are propagated in a non-uniform atmosphere they suffer refraction due to variations in wind velocity and temperature with altitude. Assuming that far distant from the body the shock waves are travelling at the speed of sound normal to themselves, then a simple calculation[4] shows that the condition for the waves originating at height h_1, say, to be refracted parallel to the ground at the height h_2 is (*see* Fig. 29)

$$\frac{a_1 \sin \beta_1 + v_1}{a_2 \sin \beta_2 + v_2} = \sin^2 \phi_1 \quad . \quad . \quad (21)$$

where β is the angle the sound ray (*i.e.* the normal to the Mach wave), makes with the ground normal; ϕ is the angle the sound ray makes with the ground normal when the wind velocity is included; a is the speed of sound; v is the horizontal component of the wind velocity. Suffix "1" refers to conditions at a given altitude h_1 and suffix "2" to the altitude h_2 at which the rays are parallel to the ground.

If θ is the angle the flight path makes with the ground normal when the body speed is U_1, then if $v=0$ and μ is the Mach angle,

$$\beta = \phi = \mu - \frac{\pi}{2} + \theta \quad . \quad . \quad . \quad (22)$$

and equation (21) reduces to

$$U_1 = \frac{a_2 \sin \beta_1}{\sin \mu_1} \quad . \quad . \quad . \quad (23)$$

Thus when θ equals $\pi/2$ equation (23) shows that the waves will be refracted back at height h_2 where the speed of sound a_2 is equal to the speed of the body U_1 at height h_1.

If an aircraft* is in a shallow dive at $\theta = 75°$ to the ground normal at $h = 40{,}000$ ft., and the Mach number at this instant is 1·1, equation (23) shows that refraction of the rays upwards will commence at 25,000 ft. Whether or not the remaining waves will reach the ground depends on the spatial extent of the wave which in turn is critically related to the time history of the aircraft motion.

9.3. STEADY FLIGHT AT SUPERSONIC SPEEDS

Although at first sight this problem should afford a simple solution for the time sequence and the intensity of noise produced by the shock waves passing a ground observer, it still requires a detailed knowledge of the shock pattern around the complete aircraft. Once this is known the solution follows from equations (16) to (19) inclusive. It is worth noting (*see* Fig. 30) that for a given aircraft at a given height the pressure increase across the shock waves does not increase rapidly with increase in Mach number. When the flight path is parallel to the ground (*i.e.* $\theta = \pi/2$) equation (23) shows that the shock wave pattern will not penetrate below altitudes at which the local speed of sound is greater than the forward speed of the aircraft.

It can be shown from equation (21), for bodies moving at uniform supersonic speed and at constant altitude, that it is only for forward speeds at low supersonic Mach numbers that the shock waves are refracted back to higher altitudes. Thus for flight just above sonic speed at high altitude the shock waves will not be transmitted to ground level. The noise heard by a ground observer would then be limited to that of the jet etc.

*By definition, this line, along which the component of the source speed is sonic, is normal to a Mach wave.

*In this example the aircraft is represented as a point source. The atmosphere is assumed to be the Standard Atmosphere.

10. Future Problems Related to the Noise from Bodies Flying at Supersonic Speeds

Some of the more important problems are discussed which in all probability will require consideration before frequent supersonic flights at both low and high altitudes could be readily tolerated over towns and cities.

10.1. GROUND LEVEL EFFECTS

It has been shown that for an aircraft flying at supersonic speeds the shock waves, which are formed around the aircraft, will be transmitted, in general, to ground level. The intensity of these shock waves increases greatly, not as might have been expected from increase in speed, but from a decrease in the altitude of flight. The time interval for the passage of these shock waves will usually be small, but it must not be overlooked that the pain and/or physical distress to persons exposed to shock waves of frequent occurrence may not be tolerable. It is stated in Ref. 23 that a high noise level of 140 decibels above 0·0002 dyne/cm.^{2} causes physical pain whereas a noise level of 160 decibels causes mechanical damage* to the inner ear†. These values of noise level correspond to pressures about 4·0 and 40 lb./ft.^{2} root mean square respectively. It can be shown from Fig. 30, however, that provided that aircraft in straight and level flight at supersonic speeds operate at altitudes above 5,000 ft. these values of pressure excess are unlikely to be exceeded. If a limit of 120 decibels above 0·0002 dyne/cm.^{2} is set then aircraft must operate at altitudes above 20,000 ft. at a Mach number of 2·0 and above 22,000 ft. at a Mach number of 3·0‡. There still remains the problem of assessing the allowable height above which aircraft manoeuvres, such as diving, must be restricted in order to ensure that the shock waves reaching ground level have a pressure excess below the limiting values. It has been stated in Section 7 that the pressure change across the shock waves emitted by an aircraft in a vertical dive, during which supersonic speeds were reached for a finite time, can be calculated approximately as follows. The pressure change at h ft. below the point on the flight path at which the maximum supersonic speed was reached, is assumed equal to the similar pressure change at a normal distance of h ft. from the same body moving at a steady Mach number equal to that of the maximum Mach number during the dive. It immediately follows that the same conditions for noise abatement apply to aircraft both in steady and diving flight. *Thus if a limit of 120 decibels above 0·0002 dyne/cm.^{2} is set, the tentative conclusion is that aircraft must fly supersonically at altitudes in excess of 20,000 ft.*

*This figure probably depends on the time duration of the noise.

†Nothing has been said relative to the damage of property by shock waves. It is felt, however, that this problem has been discussed much more fully in papers relating to the damage of buildings exposed to high explosive blast. In this connection it is worth nothing that 160 decibels noise level corresponds to a pressure about 40 lb./ft.^{2} root mean square.

‡These figures are based on the crude assumption that the aircraft can be represented as a body of revolution of fineness ratio 0·1 for the purpose of estimating the strength of its shock waves at large distances from the aircraft.

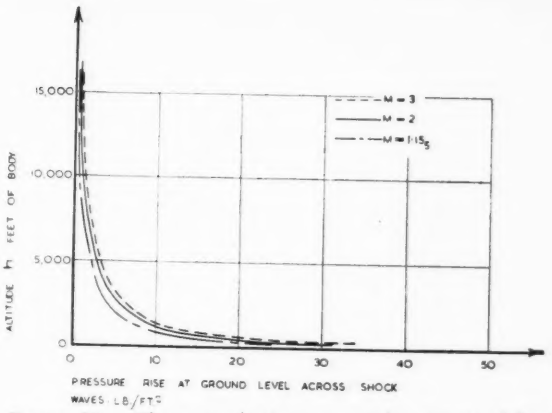


FIGURE 30. The approximate pressure rise at ground level across the bow wave of a body of revolution moving in steady flight at constant altitude h with Mach number M ($l = 30$ ft., $\delta = d/l = 0·1$).

10.2. FLYING PROBLEMS

Some of the more obvious problems which must arise from the flight of aircraft at supersonic speeds are considered here.

It has been shown that the tail shock waves move towards the nose of a body as it decelerates below the critical Mach number. The pressure changes across these shock waves will, in general, be very much greater than 40 lb./ft.^{2} and it is therefore pertinent to ask the question as to whether or not the pilot, crew, and passengers will experience a very loud explosive bang as these shock waves travel over the body. The probable answer is that the passage of the shock wave will be heard but it seems likely that the increase in noise level and the time duration will be decreased and increased respectively as compared with booms heard at ground level. This is inferred from the fact that the pressure rise across the shock wave suffers appreciable diffusion in the subsonic viscous boundary layer adjacent to the body surface.

A similar problem relates to the noise experienced inside the cabin of a low speed aircraft as an aircraft moving at supersonic speeds flies past. The separation distances of the two aircraft are assumed to be less than four miles. (If the distance is greater the problem can be discussed on similar lines to that described in 10.1.) Although in such cases some diffusion of the pressure rise across the shock waves, which strike the low-speed aircraft, still occurs in the viscous boundary layer adjacent to the surface of the low-speed aircraft, the amount of diffusion will probably be insufficient to suppress the boom. To avoid unpleasant or even dangerous effects supersonic flight of aircraft may have to be limited to the region outside a radius of at least four miles from either the nearest aircraft or ground level.

Although it is outside the scope of this paper to discuss the problems of stability and control of aircraft in accelerated and retarded flight at subsonic and supersonic speeds consequent on the movement and/or passage of shock waves across the wings or body there can be little doubt that these effects are important. These problems are made more difficult since the theory has

yet to be completed and relevant experiments in the wind tunnel are difficult to perform. The best approach is probably that of free flight experiments under conditions of fixed acceleration and retardation. A point that may need consideration is the possible effects on the control characteristics of a low-speed aircraft as shock waves, from passing supersonic aircraft, travel over their control surfaces. It is clear that the advent of supersonic flight will bring with it a number of problems and possibly hazards of a kind that it has not before been necessary to consider seriously.

11. Conclusions

(*i*) It has been shown that the noise problem associated with an aircraft flying at supersonic speeds depends primarily on the shock wave pattern formed by the aircraft.

(*ii*) When a body accelerates to supersonic speeds three main shock waves are formed, the bow wave, the front tail wave and the rear tail wave. The existence of the rear tail wave and related phenomena has been established from a theoretical discussion of the Mach waves generated by an accelerated and retarded source and experimentally by the use of towed models in a hydraulic analogy tank. The shock waves are each of finite dimensions which depend on the time history of the motion. It is noted that the steady shock wave pattern is established, strictly speaking, only after the steady motion has persisted for an infinite time.

(*iii*) When the body now decelerates to subsonic speeds below the critical Mach number it is shown that (*a*) the bow wave moves away from the nose of the body when the speed has fallen to a low supersonic Mach number, (*b*) the front tail wave changes shape and moves slowly towards the nose of the body and separates when the speed has fallen below the critical Mach number, (*c*) the rear tail wave moves towards the tail of the body, eventually travels over the body and follows in the wake of the bow and front tail waves. Under favourable conditions the rear tail wave coalesces with the front tail wave before the speed of the body has fallen below the critical Mach number.

(*iv*) An analysis of the time sequence and intensity of these moving shock waves, which are formed, say, by an aircraft diving from a high altitude when the Mach number exceeds unity for a limited period, shows that they must be the cause of the booms experienced recently by ground observers.

(*v*) The effects of these shock waves, formed by bodies in both steady and unsteady flight, on people on the ground and near other flying aircraft are analysed. It is shown that, provided that aircraft flying at supersonic speeds up to Mach numbers of 3, restrict their flights to altitudes greater than 22,000 ft., and are at least four miles from the nearest aircraft, the noise level experienced by observers will be less than 120 decibels (reference pressure 0·0002 dynes/cm.^{2}). This is based on crude assumptions as to the size of the aircraft as a source of disturbance and neglects the time duration of the noise involved. Further experiments are required to assess the nuisance or damage caused by the propagated disturbances.

ACKNOWLEDGMENT

The authors wish to thank many of their colleagues for help and criticism relating to the preparation of this paper. The subject has attracted wide and considerable interest and it must be acknowledged that many of the ideas mentioned in this paper have arisen out of discussions both inside and outside the College of Aeronautics.

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TECHNICAL NOTES

The increasing flood of technical information makes it difficult to publish even abstracts of such information and it has become still more difficult to publish technical items of information which do not reach the status of full-length papers.

Under this general heading of TECHNICAL NOTES it is hoped that members of the Society, and indeed all those who read THE JOURNAL, *will help in contributing just those very items of useful information which normally might not see the light of the printed page.*

There will be no set form for these Notes. They may be illustrated or not. They can be short papers of a thousand or two thousand words; or abstracts and comments upon unpublished papers or upon published papers with a limited circulation; or notes of some interim results of research in hand and notes for further research; or in the form of a letter raising technical points or asking questions; or letters commenting on Notes published.

These pages are intended to be a technical forum where members can argue and discuss; where they can inform and be informed; and pass on their own experience, or air their technical difficulties. Contributions will be eligible for THE JOURNAL *Premium Awards and they will be published as soon as possible after they are received.*

No member need ever say that his particular subject does not get discussed in the pages of THE JOURNAL. *He can always raise it himself, for these pages are his pages.*

This month we publish notes on corrections to linear accelerometers and on an apparatus used for remote measurement of forces and moments, a simple method for estimating the stability derivative l_v, a method for calculating space free resonance modes, and to our regret, a correction to one of the technical notes in the April 1953 *Journal when captions to two figures in the note by J. K. Oaks were transposed.*—THE EDITOR.

Reduction of Flight Test Data From Linear Accelerometers

by

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THE PROBLEMS discussed in this note refer to the simplest case of the use of linear accelerometers, in which the flight path is in the vertical plane of symmetry of the aeroplane, and the acceleration normal to the path is to be determined.

Generally two facts are neglected:—

(*i*) That the accelerometer senses along an arbitrary body axis Z_B (Fig. 1), instead of along the wind axis Z (normal to the path).

(*ii*) That the accelerometer is not placed exactly at the c.g. of the aeroplane but at some point A, having co-ordinates x_A and z_A in the body axes.

The equation of motion, for wind axis normal to the path, is

$$\frac{W}{g} V\dot{\gamma} = \Sigma Z = \frac{W}{g}(n_Z g) \quad . \quad . \quad . \quad (1)$$

As the accelerometer is sensing about the body axis Z_B, inclined at the angle α to the wind axis Z, it will measure

$$(n_Z)_B g = n_Z g \cos\alpha + g\cos\theta \quad . \quad . \quad (2)$$

where θ is the angle between Z_B and the vertical.

From equation (2)

$$n_Z = \frac{(n_Z)_B - \cos\theta}{\cos\alpha} \quad . \quad . \quad . \quad (3)$$

When the accelerometer is not placed at the c.g. but at the point A, it is subject to an additional motion about the c.g.

The acceleration of the point A, with respect to the c.g. can be conveniently replaced by its tangential and normal components

$$a_t = r_A\ddot{\theta} \quad . \quad . \quad . \quad . \quad (4)$$

and

$$a_n = r_A\dot{\theta}^2 \quad . \quad . \quad . \quad . \quad (5)$$

where r_A is the distance of the accelerometer from the c.g.

Projecting a_t and a_n on the body axes X_B and Z_B and substituting $\sin\varepsilon = x_A/r_A$, $\cos\varepsilon = z_A/r_A$, gives

Received 23rd April 1953.

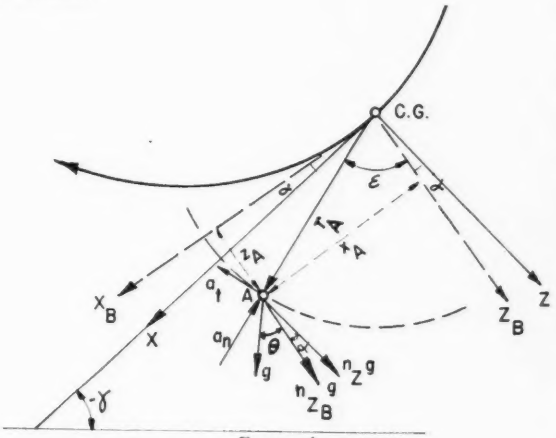

FIGURE 1.

From acceleration	*Component along axis* X_B	Z_B
$a_t = r_A\ddot{\theta}$	$r_A\ddot{\theta}\frac{z_A}{r_A} = z_A\ddot{\theta}$	$-r_A\ddot{\theta}\frac{x_A}{r_A} = -x_A\ddot{\theta}$
$a_n = r_A\dot{\theta}^2$	$-r_A\dot{\theta}^2\frac{x_A}{r_A} = -x_A\dot{\theta}^2$	$-r_A\dot{\theta}^2\frac{z_A}{r_A} = -z_A\dot{\theta}^2$

Thus the reading of the accelerometer $[(n_Z)_B g]$ given by equation (2) has to be corrected by

$$\Delta[(n_Z)_B g] = -(x_A\ddot{\theta} + z_A\dot{\theta}^2) \quad . \quad . \quad (6)$$

Substituting equation (7) into equation (2) yields

$$(n_Z)_B g = n_Z g\cos\alpha + g\cos\theta - (x_A\ddot{\theta} + z_A\dot{\theta}^2) \quad . \quad (7)$$

The actual acceleration normal to the path expressed in "g's" is

$$n_Z = \frac{(n_Z)_B - \cos\theta + (x_A\ddot{\theta} + z_A\dot{\theta}^2)/g}{\cos\alpha} \quad . \quad (8)$$

Other cases, like turn and the most general three-dimensional case, can be developed similarly.

Differential Inductance Telemeter Equipment for Force and Moment Measurements

by

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THIS note describes apparatus which has been used for remote measurements of forces and moments on models on the Whirling Arm at the National Physical Laboratory. Good short-term stability, independent of mains frequency and voltage variations, has been obtained with simple apparatus. Descriptions are included of the differential inductance bridge, a stable 1 kc./sec. oscillator used therewith, and a regulated power supply for the oscillator. General comments are made on problems involved in the force and moment measurements.

1. INTRODUCTION

The measurement of a force or moment usually resolves into the measurement of the deflection of a spring opposing the force or moment. For many years use has been made of the change of reluctance of the magnetic circuit of a coil to measure the change in position of a piece of soft iron forming part of the magnetic circuit. The conversion of a movement into a change of inductance has the advantage over the conversion into a change of capacitance, that for reasonable sensitivity no physical restraint need be placed on the moving element. A sensitive capacitance gauge for use with very long screened leads would need to have a very large capacity to swamp the lead capacity, and this type of gauge would normally be cemented to the spring under strain, introducing elastic constraint subject to hysteresis. In one respect, however, the capacitance strain gauge has an advantage over the inductance strain gauge, namely that the impedance of the condenser generally is very nearly a pure reactance whereas practical inductance gauges include in their impedance an important element of resistance, mostly ohmic (independent of frequency) but partly of hysteresis and eddy current origin, varying complexly with frequency. It is this resistive element in the impedance which makes it imperative to use a bridge source of constant frequency. Before 1940, the 50 c./s. mains was suitable as a bridge source; reference books usually quoted the frequency of the mains as seldom departing from the nominal value by as much as two parts in a thousand. In recent years this standard of performance has, of necessity, been abandoned and, to obtain good accuracy in force telemetering, the author found it necessary to use a source of constant frequency and, for reasons mentioned later, of constant amplitude.

2. THE INDUCTANCE BRIDGE

The type of bridge used in this work has been described previously[1]. Its main features are that out-of-balance current is indicated in sense as well as magnitude, and the rectifiers used are polarised by the bridge current to reduce their forward resistance.

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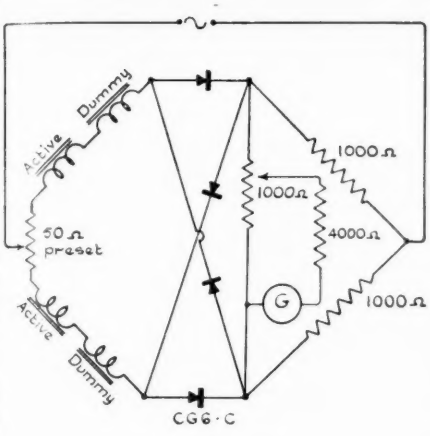
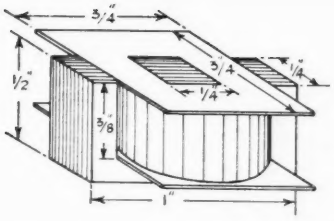
In Fig. 1(*a*), it will be seen that two bridge arms each include one of the pair of differential active coils (*i.e.* those indicating the strain to be measured) together with one of the pair of differential dummy coils. In this arrangement the capacities of the screened leads to the active pair of coils are equally divided between two arms and do not need to be balanced out with trimmer condensers. The bridge is normally used in the null condition, the bridge balance being restored by the movement of a soft iron plate between the pair of dummy coils. The two ratio arms are equal non-inductively wound resistances. It is not possible to put the dummy coils in the other bridge arms, in place of the resistances, without very seriously reducing the sensitivity to inductance changes, and increasing the sensitivity to resistance changes.

The rectifiers chosen were type CG6.C in the B.T.H. wire-ended crystal rectifier series. These had a high factor of safety in this application, being used with a negligible inverse voltage and a current of 20 mA. approximately, being rated for a maximum inverse voltage of 50, with a continuous safe working current of 50 mA. and a maximum surge current of 400 mA. Four were selected, having as nearly equal forward resistances as possible, by connecting each, in turn, in series with a 1·5 volt cell and a low-resistance milliammeter; those chosen gave currents between 20 and 22 mA. This was necessary since the rectifiers formed part of the bridge arms. To avoid slight changes of rectifier resistance with temperature arising from draughts, the rectifiers were enclosed in a metal can of 1·5 in. cube with an insulating lid, connections to the rectifiers being through brass studs piercing the lid. The can was lightly packed with cotton wool to minimise internal convection. Provision was made for balancing slight inequalities of rectifier and coil resistances through a 50 ohm pre-set potentiometer between the coil arms.

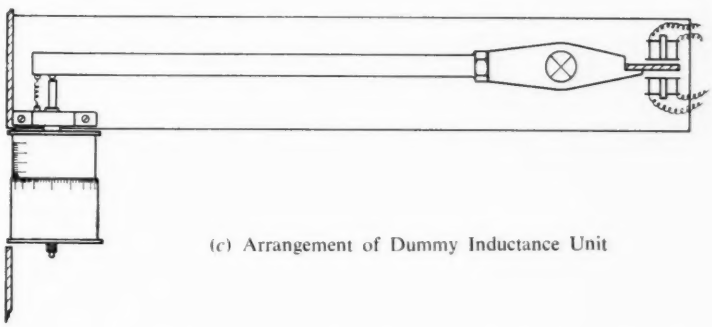
Figure 1(*b*) illustrates the coils used, which were wound on bobbins made to fit 0·015 in. thick Mumetal laminations with dimensions shown in the diagram. These laminations were the smallest readily obtainable from the Ministry of Supply E.D.C. Stores at the time. A winding of 1,100 turns of 38 S.W.G. enamelled copper wire gave an inductance of 50 millihenries and a reactance to resistance ratio (Q) of 6·7 measured at 1 kc./sec. With the soft iron plate against the coil, completing the magnetic circuit, the inductance was approximately doubled. It will be appreciated that the coil laminations should be clamped, and the coils located with a non-metallic material lest eddy current losses should increase the effective resistance of the coils and lower the bridge sensitivity. The plates used to change the coil inductances were of Swedish soft iron, $\frac{3}{32}$ in. thick and shaped to cover amply the magnetic core of the coil unit, with provision for attachment to the lever



(*a*) Bridge Circuit



(*b*) Single Inductance Element



(*c*) Arrangement of Dummy Inductance Unit

FIGURE 1

which moved as a result of the moment or force to be measured. The gap between each coil face and the plate in the mid-position was normally 0·1 in.

Figure 1(*c*) illustrates the arrangement of the dummy coil unit and micrometer. The second soft iron plate was screwed to the short end of a lever of five to one ratio, pivoted on a precision-fit bearing which allowed free angular movement without lateral slackness. At the other end of the lever a polished steel ball, fixed into the lever, was held in permanent contact with the end of the shaft of a large drum micrometer by a light spring. The entire unit was positioned relative to a rectangular hole in the front panel of the bridge chassis so that the micrometer drum could be operated by fingertips and the scale read conveniently.

A taut-suspension reflecting galvanometer of 200 ohms resistance and 1·6 cm. per microampere sensitivity was used with the bridge. This was well able to withstand the vibration sustained when the mobile rack, housing the equipment, was moved. A galvanometer sensitivity control potentiometer was included. All readings were taken at full sensitivity although intermediate sensitivities were used, to safeguard the galvanometer, while the force was being changed. Use was made of the zero position of the potentiometer to check the galvanometer zero without reducing the signal voltage, since errors were likely to occur in resetting the signal voltage to the original value.

3. REQUIREMENTS FOR THE OSCILLATOR

It will be seen, from Fig. 1(*a*), that, for each half-cycle of the source voltage, the bridge may be considered as two ratio arms and two arms, each including two coils and one rectifier. In electrical terms these latter arms represent an inductance (*i.e.* reactance proportional to frequency), a stray capacitance (*i.e.* reactance inversely proportional to frequency) and a resistance (part of which varies with the current through the bridge). The galvanometer will indicate a balance when the values of a complicated function of the resistances and reactances of each arm are equal. There is no unique solution for the resistances and reactances at balance and neither the reactances nor the resistances need to be separately equal. Supposing that a balance were obtained with the reactances slightly unequal and the resistances correspondingly unequal. Then any slight change of frequency would alter the reactances but not the resistances, and any change of source voltage would alter the resistances (*i.e.* of the rectifiers) but not the reactances and so, in either case, the bridge would become unbalanced. To prevent errors of this kind a source of constant frequency and amplitude was used to supply the bridge.

Although, in theory, the sensitivity of the bridge would increase with rise of source frequency, the shunting effect of the high capacitance of the 100 ft. pairs of screened leads to the active coils used in the Whirling Arm would have reduced the sensitivity of the bridge, had too high an audio frequency been used. The author decided to use a frequency of 1 kc./sec.

4. THE OSCILLATOR

The oscillator used was of the Wien Bridge controlled type (Fig. 2). The frequency is governed by the values of the resistances and condensers, R and C. It can be shown readily that the output voltage (across R and C in parallel) will be in phase with the source voltage (across both R and C in series and R and C in parallel) at one frequency only, given by the equation $2\pi fRC = 1$, and the output voltage will be one third of the source voltage at this frequency. The amplifier valves merely restore this three to one reduction and feed the restored signal back, in the correct phase, as the source voltage. The resistance ratio arms completing the bridge consist of a S.T.C. Thermistor (Type A5513/100) and the 5 kilohm cathode resistance of the

first valve. The thermistor is a fast responding semi-conductor element, whose resistance decreases sharply with an increase of current, the temperature coefficient of resistance being highly negative.

When a signal of approximately 30 volts is across the Wien Bridge, the thermistor resistance will be just 10 kilohms, and the A.C. potential across the bridge output (grid to cathode of the first valve) will be zero, apart from the small signal required for the amplifier. Any change of bridge signal would change the current through the thermistor, thus altering the thermistor resistance, and this would, in turn, correct the oscillator signal to the 30 volts needed to maintain oscillation. By not exceeding this output, overloading of the valves is avoided and the generation of undesirable harmonics prevented. A more complete description of the operation of this type of oscillator has appeared elsewhere[2].

To ensure good frequency stability the bridge condensers (C) were of high stability silvered mica pattern (0·015 microfarads) and the bridge resistances (R) were of high stability type (10·56 kilohms). Since the thermistor resistance determined the output voltage from the oscillator, the thermistor was mounted, close under the chassis, away from valves and other heat generating elements, and the power supply chassis was mounted above the oscillator chassis, on the rack.

The oscillator output stage was of conventional design. The beam tetrode power valve was coupled to a tapped output transformer designed to match 25, 100, 500 and 2,000 ohms loads at the oscillator frequency. In this way the oscillator could be used to feed other types of bridges, of differing impedances, when required. The output was taken from a Post Office jack coupled to the transformer tappings by a two-pole four-way switch, the second pole being used to connect resistances equal to the four-loads, in turn, across the transformer when the jack plug was removed. This measure avoided the possibility of damage to the output valve through the sudden removal of the output load. For use with the bridge, a 25 volt full scale, panel mounting, A.C. voltmeter was connected across the 500 ohms transformer winding corresponding to the load of the bridge.

5. OSCILLATOR POWER SUPPLY

To make the oscillator output voltage even less dependent on the mains voltage, and completely free from mains hum, a regulated power supply was used (Fig. 2). A design by R. G. Chalmers, of Electronics Section, N.P.L., which had proved successful in other fields, was copied and added to the transformer, rectifier and ripple filter previously purchased. Since the regulating unit was designed to operate from a D.C. input of 450 volts (after the filter), the filter input choke was shunted by a resistance (R_s) found, by trial and error, to produce the correct voltage.

The power supply was adjusted for use by setting two pre-set potentiometers in conjunction, the one, in the output resistance network, to give an output voltage of 250, and the other, shunting the 6L6 valve, to eliminate the residual hum, as indicated by a high gain cathode ray oscilloscope connected to the output through a condenser. This second potentiometer controlled the amount of out-of-phase ripple mixed with the output, and could be set to neutralise the ripple completely, after which the output voltage needed slight readjustment. To avoid delays through failure of any components in the regulation unit, this unit was duplicated, the two units being fed, through separate fuses, from the ripple filter output.

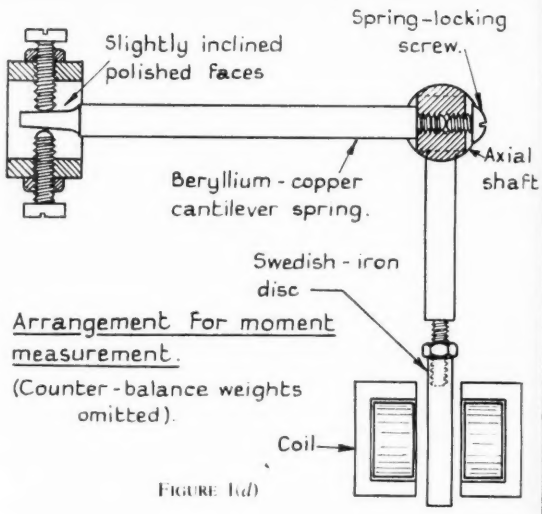


FIGURE 1(d)

6. MECHANICAL ASPECTS OF MOMENT MEASUREMENT

Experience in the measurement of small moments on the Whirling Arm, gained by Dr. A. S. Halliday and Miss D. K. Cox, over several years might prove of value to newcomers in this field. They found that the shaft, attached to the model, about which the moment was to be measured, needed to be mounted in precision self-aligning ball races, free from any radial slackness and, for preference, "run in" with Jeweller's Rouge while the bearing was rotated quickly in a lathe. The bearings had to be readily accessible, in order that they could be frequently removed for washing in benzene, to extract dust and metallic particles, and subsquently lubricated with the finest typewriter oil. This ensured the absolute minimum of friction and was done every few days, whenever zero readings were difficult to repeat.

A cylindrical cantilever spring was screwed firmly normal to the shaft; in recent experiments beryllium-copper had been found a suitable material, free from hysteresis. At the end of the spring remote from the shaft, two slightly inclined plane faces were ground parallel to the shaft and worked to a mirror finish. It would probably prove most valuable to have these faces heavily chromium plated and polished. These faces of the spring were clamped by normal, opposing, hardened screws with polished hemispherical ends, the screws being just tight enough to prevent "chatter" when the spring was tapped, not tight enough to dent the faces of the spring. The polished faces were slightly inclined one to another to counteract the tendency of the clamping screws to dig into the spring as the inclination

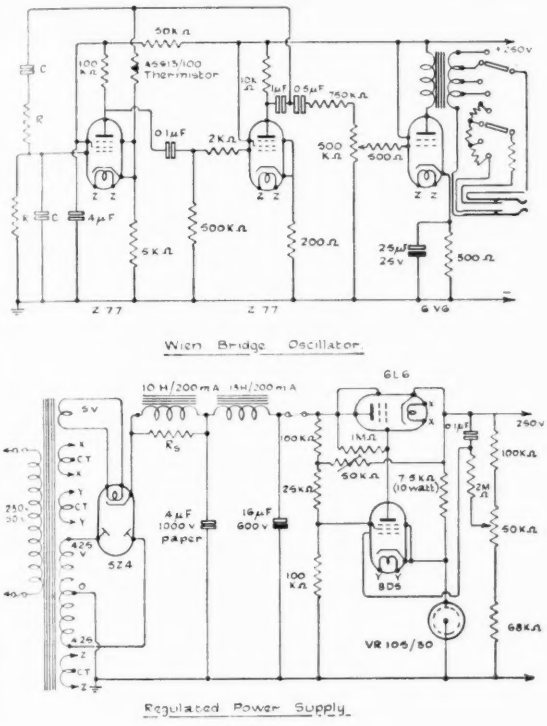


FIGURE 2

of the spring changed when bending under a load. In this way, the moment to be measured was converted linearly into a rotation of the shaft.

Another lever was screwed normal to the shaft, and at its end was attached one of the soft iron plates, the plane of the plate passing through the shaft. The differential pair of active coils were fixed with the open core faces each 0·1 in. from the plate on opposite sides. In this way the moment was converted into a movement of the plate. By making several cantilever springs of differing diameters the maximum plate deflection was restricted to about 0·02 in. for the maximum moment to be measured (Fig. 1(*d*)).

7. USING THE APPARATUS

After connecting the various units the oscillator and power supply should be switched on and left a few minutes to settle down. Then, using thickness gauges, the plates between active and dummy coils should be accurately centralised. The oscillator signal voltage to the bridge should be set to the value intended to be used (say 15 volts for normal working or 25 volts for most sensitive working). Then the galvanometer sensitivity control should be increased, eventually to the maximum, while adjusting the 50 ohm pre-set potentiometer until the galvanometer deflection is zero. Having thus balanced out the inequalities in the resistances of the coils and rectifiers for this one bridge signal voltage, the pre-set potentiometer should not be altered, unless a different signal voltage is to be used. During experiments on the Whirling Arm, galvanometer zero readings (sensitivity control reduced to zero) were checked frequently and "no-load" zero micrometer readings were checked as often as possible, usually after about five minutes. Calibration was always direct; a moment applied to the model and the micrometer reading for no galvanometer deflection taken. Calibrations were checked every few days. One great advantage of this system of measurement is that the angular deflection of the shaft holding the model is readily calculated by assuming that the dummy soft iron plate moves a distance equal and opposite to that of the active soft iron plate, when the bridge is balanced. Knowing the relevant leverage ratios a correction to the incidence of the model under load is comparatively simple.

8. PERFORMANCE

Although no electrical measurements were made of frequency and output voltage stability, no trouble was experienced with drift. Whenever difficulty was experienced in repeated zero readings, the fault was found to be mechanical (*i.e.* slackness through vibration, friction in ball races, etc.).

The sensitivity of the apparatus will depend on the coil to plate spacing. Using 0·1 in., which gave a fair range of linearity of calibration, and a bridge signal of 25 volts, 1 mm. on the galvanometer scale represented approximately 24 millionths of an inch, a linear gain of 1,650, with circuit values given in Fig. 1(*a*). Since the galvanometer was of fairly low sensitivity and the galvanometer series resistance was high (to make bridge balance independent of sensitivity control position) a higher linear magnification could have been obtained readily but was not found necessary.

ACKNOWLEDGMENT

This work was done in the Aerodynamics Division of the National Physical Laboratory, and the author acknowledges the permission of the Director to publish.

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A Simple Rolling Method For l_p

by

P. T. FINK

(Imperial College)

AERODYNAMIC THEORY may be used with reasonable confidence to estimate the low-speed value of the stability derivative l_p for wings of most plan forms under quasi-steady conditions so long as viscous effects are unimportant. Wind tunnels tests are made to cover other cases such as the partially stalled swept wing, but the writer has heard of a difficulty

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encountered by a firm when using the free-rolling method[1]. A variant of that technique in which this difficulty is avoided and which has been used at Imperial College for some years may be of interest.

In the free-rolling method of Ref. 1 a wind tunnel model, fitted with ailerons, is mounted with freedom to roll. The ailerons are deflected and their rolling moment L is taken out with a wire and then measured on a balance. The wire is then removed and the model quickly attains the steady rate of roll L/L_p unless there is marked irregularity of the tunnel stream. However, the assumption that the aileron rolling moment takes its static value L during the rotation becomes inadequate for appreciable angles of incidence.

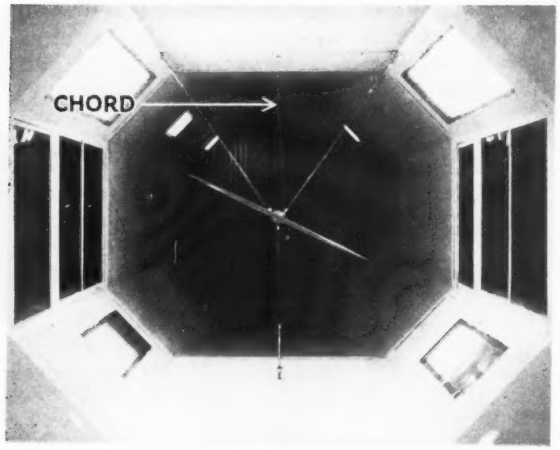

FIGURE 1.

In the "gravity" rolling method, used at Imperial College, the external moment is applied by a chord which is attached to a falling mass outside the tunnel. It is easy to ensure that the moments due to friction in the model support and pulleys, if these are necessary, are small and the uncertainty of the applied moment is now removed. The probable experimental error may be kept within two per cent. A secondary advantage of this and any other method[2] in which the applied moment is non-aerodynamic is that rolling moments due to tunnel stream irregularity are easily overpowered. Fig. 1 shows the set-up in the new 5 ft. × 4 ft. wind tunnel at the College; this is used by students to measure the damping in roll of a wing of elliptic plan form. The experimental value at zero incidence is five per cent. below the lifting-line theory estimate.

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A Method of Calculating Space Free Resonance Modes of an Aircraft

by

B. A. HUNN

(Senior Mathematician, Hawker Aircraft Ltd.)

THE PROBLEM of deducing resonance modes of vibration of an aircraft in free space is a concomitant of flutter calculations if the number of degrees of freedom used is to be small. When the structure is complex in that it involves wings, fuselage and tailplane, each of which possesses infinitely many normal modes, it becomes apparent that the number of point masses which must be considered, in constructing a dynamical equivalent to give a sufficient coverage of the frequency range in which flutter is likely, is very large. For example, it may be necessary to use four rods per wing and per tailplane and four point masses on the fuselage. This would involve $8+8+4$ degrees of freedom, and if the usual technique of characteristic roots is used it would be necessary to consider a characteristic root matrix of order 20×20.

The method of overcoming this difficulty is considered here in such a way that the high order matrix is effectively sub-divided into more manageable sections and the resulting individual solutions are combined to give the overall pattern.

GENERAL PRINCIPLES

For any individual member of a complex structure it is possible to deduce resonance modes of vibration. In particular, given a structure of extension in the xy-plane to be vibrated in the z-direction, the shape of vibration in any given normal mode z_n can be deduced in the form

$$z = z_n(x, y)$$

where the origin may be chosen arbitrarily.

Now any arbitrary shape of deformation of the component part may be represented in terms of linear combinations of its own normal modes,

i.e.
$$z(x, y) = \sum_{r=1}^{\infty} q_r z_r(x, y)$$

where all the modes are related to the same standard position, and q_r are determinate multipliers. In practice, however, the number of modes which occur on an aircraft whose frequencies are less than a certain upper limit (which will be specified) is small. In particular, on any specific component part the number is very much less than the number of point masses which must be used for the dynamical model in order to give an adequate representation. The characteristic root matrix may be represented in the form

$$[(\omega^2 A_{rs} - E_{rs})\delta_{rs}]\{q_s\} = \{0\},$$

where
$$\delta_{rs} = 0, \quad r \neq s$$
$$\delta_{rs} = 1, \quad r = s.$$

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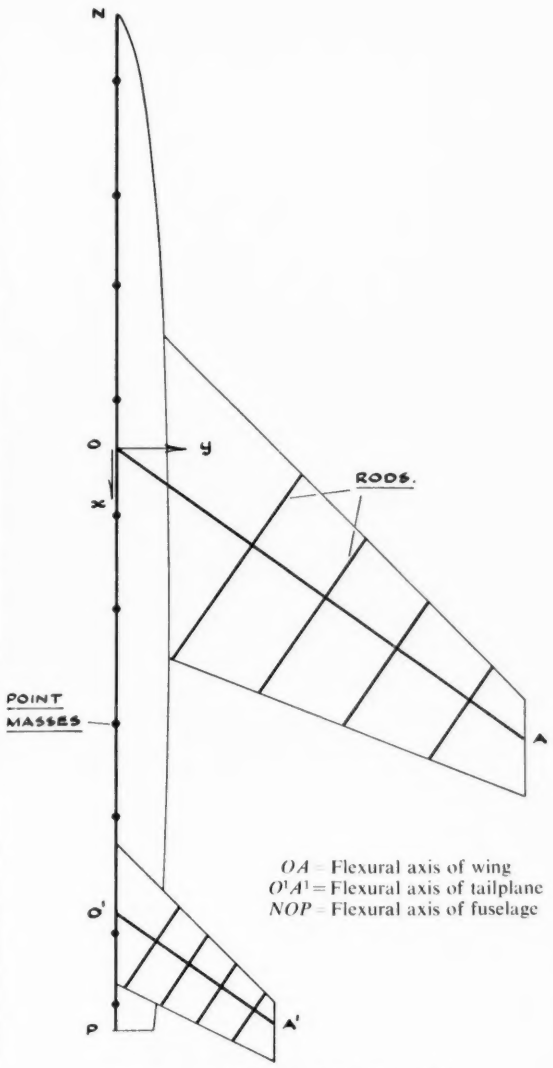

FIGURE 1. Half of hypothetical aircraft.

Using the results that $E_{rr}=\omega_r^2 A_{rr}$, gives a characteristic matrix whose diagonal terms are

$$A_{rr}(\omega^2-\omega_r^2).$$

Given an arbitrary shape to fit at a frequency ω, it is found that

$$[A_{rr}(\omega^2-\omega_r^2)]\{q_r\}=\{z_r\}=\text{generalised forces},$$

from which it follows that

$$q_r \propto \frac{1}{(\omega^2-\omega_r^2)}.$$

Thus the general result is that the component normal modes of a vibration shape at frequency ω have amplitudes inversely proportional to the differences of the squares of their own circular frequencies and the circular frequency of vibration. It follows that if only those modes are considered which fall within the range of frequency 0 to F say, for the composite structure, then an adequate representation of the component parts can be found if they are defined elastically in terms of only those of their normal modes whose frequency differences are small.

The genesis of these remarks is that it is extremely inefficient to represent the composite structure by means of a point mass or rod dynamical model, since the number of degrees of freedom introduced into the characteristic root matrix is far in excess of the number of effective normal modes of the component parts.

In what follows an attempt is made to deduce a dynamical model of an aircraft in terms of the effective normal modes of the wings, fuselage and tailplane considered as separate entities. It will be assumed that these component modes are calculable under root-fixed conditions.

THE NORMAL MODE MODEL

Referring to Fig. 1, let it be supposed that an adequate dynamical model of the aircraft be given by a weightless skeleton structure OA, $O'A'$, NOP in which is concentrated the elastic properties and to which are attached the rods and point masses which reproduce approximately the mass and inertia distribution.

For convenience the point O is used as a datum, such that in the free space modes O has a vertical displacement z_0 and a pitch angle of the tangent at O to $NOO'P$ of amount θ_0. Denote by $z_{r(1)}(x, y)$ the modal shapes of the wings in the root-fixed condition. Let $z_{r(2)}(x, y)$ denote the modal shapes of the tailplane with the point O' likewise fixed. For convenience the fuselage will be divided into two parts NO and $OO'P$ and the normal modes of NO are denoted by $z_{r(3)}(x, y)$ and those of $OO'P$ by $z_{r(4)}(x, y)$.

Taking O as the origin of Cartesian co-ordinates with x positive aft, y positive to starboard and z positive downwards, θ_0 is defined as positive nose up. Now any displacement $z(x, y)$ of the wings may be given the form

$$z(x, y)=z_0+x\theta_0+\sum_1^{n_1} q_{r(1)}z_{r(1)}(x, y)$$

where n_1 is the upper limit imposed upon the wing root-fixed modes.

Similarly for the fuselage:—

$$z=z_0+x\theta_0+\sum_1^{n_3} q_{r(3)}z_{r(3)}(x, y) \quad \text{for } NO$$

and

$$z=z_0+x\theta_0+\sum_1^{n_4} q_{r(4)}z_{r(4)}(x, y) \quad \text{for } OO'P.$$

Now for the tailplane it is necessary to introduce the movement of O' due to the modes $q_{r(4)}\ z_{r(4)}(x, y)$. The displacement at O' is

$$z(O')=z_0+OO'\theta_0+\sum_1^{n_4} q_{r(4)}z_{r(4)}(O')$$

and the pitch angle is

$$\theta(O')=\theta_0+\sum_1^{n_4} q_{r(4)}\frac{dz_{r(4)}(O')}{dx}.$$

Thus the general displacement of points on the tailplane is given by

$$z = z_0 + OO'\theta_0 + \sum_1^{n_4} q_{r(4)} z_{r(4)}(O') +$$
$$+ (x - OO')\left\{\theta_0 + \sum_1^{n_4} q_{r(4)} \frac{dz_{r(4)}(O')}{dx}\right\} + \sum_1^{n_2} q_{r(2)} z_{r(2)}(x, y).$$
$$= z_0 + x\theta_0 + \sum_1^{n_4} q_{r(4)}\left[z_{r(4)}(O') + (x - OO')\frac{dz_{r(4)}(O')}{dx}\right] +$$
$$+ \sum_1^{n_2} q_{r(2)} z_{r(2)}(x, y).$$

Clearly the strain energy of the system is given by the normal form

$$V = \tfrac{1}{2}\{2\sum_1^{n_1}[q_{r(1)}\omega_{r(1)}]^2 A_{rr(1)} + 2\sum_1^{n_2}[q_{r(2)}\omega_{r(2)}]^2 A_{rr(2)} +$$
$$+ \sum_1^{n_3}[q_{r(3)}\omega_{r(3)}]^2 A_{rr(3)} + \sum_1^{n_4}[q_{r(4)}\omega_{r(4)}]^2 A_{rr(4)}\},$$

where $A_{rr(1)}$ and so on are the coefficients of the various modes in the kinetic energy associated with the root-fixed conditions.

The kinetic energy of the aircraft when vibrating in free space is of the form

$$T = -\tfrac{1}{2}\omega^2\left\{2\sum_1^{n_1}(q_{r(1)})^2 A_{rr(1)} + 2z_0\sum_1^{n_1} 2A_{r0(1)}q_{r(1)} + \right.$$
$$+ 2\theta_0\sum_1^{n_1} 2B_{r0(1)}q_{r(1)}$$
$$+ 2\sum_1^{n_2}(q_{r(2)})^2 A_{rr(2)} + 2z_0\sum_1^{n_2} 2A_{r0(2)}q_{r(2)} + 2\theta_0\sum_1^{n_2} 2B_{r0(2)}q_{r(2)}$$
$$+ \sum_1^{n_3}(q_{r(3)})^2 A_{rr(3)} + z_0\sum_1^{n_3} 2A_{r0(3)}q_{r(3)} + \theta_0\sum_1^{n_3} 2B_{r0(3)}q_{r(3)}$$
$$+ \sum_1^{n_4}(q_{r(4)})^2 A_{rr(4)} + z_0\sum_1^{n_4} 2A_{r0(4)}q_{r(4)} + \theta_0\sum_1^{n_4} 2B_{r0(4)}q_{r(4)}$$
$$\left. + 2\sum_{r=1}^{n_2}\sum_{s=1}^{n_4} 2A_{rs(2)(4)}q_{r(2)}q_{s(4)} + z_0^2 A_{00} + \theta_0^2 B_{00} + 2z_0\theta_0 C_{00}.\right\}$$

Using the Lagrangian equations

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_r}\right) + \frac{\partial V}{\partial q_r} = 0$$

for all the unknown quantities z_0, θ_0, $q_{r(s)}$ will give $(n_1 + n_2 + n_3 + n_4 + 2)$ equations in which there are $(n_1 + n_2 + n_3 + n_4)$ with non-zero values for $\partial V/\partial q_r$.

Adopting the usual procedure where

$$\omega^2 = \frac{1}{\lambda}$$

will give a matrix of order $(n_1 + n_2 + n_3 + n_4 + 2)$ from which $(n_1 + n_2 + n_3 + n_4)$ characteristic roots can be extracted.

CALCULATION SCHEME

First construct detailed dynamical models of the wings, front fuselage, rear fuselage less tailplane, and the tailplane. For each of these dynamical models determine the first few resonance modes under root-fixed conditions. The number extracted in each case is determined by the condition that the frequency f_n of the last in each case fulfils the condition $f_n \leqslant F_{\max}$ where $F_{\max}$ for present purposes can be taken as twice the upper frequency of the range in which flutter is likely. In these root-fixed modes the terms A_{rr} and $\omega_r^2 A_{rr}$ can be calculated by the usual method. However, for the rear fuselage it is necessary in each mode to extract $z_{r(4)}(O')$ and $dz_{r(4)}(O')/dx$.

Giving the aircraft the arbitrary displacement z_0, θ_0 at O, the terms A_{r0} and B_{r0} can now be computed together with A_{00}, B_{00} and C_{00}.

Finally the terms $A_{rs(2)(4)}$ are computed. It is now necessary to construct the equations

$$A_{rr(1)}(1 - \lambda[\omega_{r(1)}]^2)q_{r(1)} + A_{r0(1)}z_0 + B_{r0(1)}\theta_0 = 0$$

for all values of r over the wings. A similar set is obtained for the front fuselage. For the rear fuselage and tailplane the form becomes

$$A_{rr(4)}(1 - \lambda[\omega_{r(4)}]^2)q_{r(4)} + 2\sum_{s=1}^{n} A_{rs(2)(4)}q_{s(2)} +$$
$$+ A_{r0(4)}z_0 + B_{r0(4)}\theta_0 = 0,$$

and over the whole aircraft

$$z_0 A_{00} + \theta_0 C_{00} + 2\sum_1^{n_1} A_{r0(1)}q_{r(1)} + 2\sum_1^{n_2} A_{r0(2)}q_{r(2)} +$$
$$+ \sum_1^{n_3} A_{r0(3)}q_{r(3)} + \sum_1^{n_4} A_{r0(4)}q_{r(4)} = 0$$

$$\theta_0 B_{00} + z_0 C_{00} + 2\sum_1^{n_1} B_{r0(1)}q_{r(1)} + 2\sum_1^{n_2} B_{r0(2)}q_{r(2)} +$$
$$+ \sum_1^{n_3} B_{r0(3)}q_{r(3)} + \sum_1^{n_4} B_{r0(4)}q_{r(4)} = 0.$$

The matrix of these equations can be manipulated by linear combinations of each to give the required characteristic root matrix.

ACKNOWLEDGMENT

The author thanks the Chief Designer, Hawker Aircraft Ltd., for permission to publish this note.

ERRATUM

Is is regretted that in the Technical Note (April 1953 Journal), "Stresses and Deflection in a Flat Plate with Clamped Edges under Normal Pressure" by J. K. Oaks, the captions to Figs. 6 and 7 were inadvertently transposed. The caption to Fig. 6 on p. 245 refers to Fig. 7 on p. 246 and vice versa.

THE LIBRARY

Reviews

PROCEEDINGS OF THE GENERAL DISCUSSION ON HEAT TRANSFER, SEPTEMBER 11th-13th 1951. *Institution of Mechanical Engineers; American Society of Mechanical Engineering 1952.*

This volume contains all the papers, nearly 100 in number, presented and the discusssion of them. It also contains Professor Colburn James Clayton's lecture entitled "Problems of Design and Research on Condensers of Vapours and Vapour Mixtures", and accounts of the introduction and closing sessions and the speeches made at the dinner. The discussion was held under the auspices of the American Society of Mechanical Engineering and the Institution of Mechanical Engineers.

Heat Transfer is a very general term covering a wide range of subjects; in recent years the number and variety of applications has increased so much that it is now quite impossible to cover an outline of the whole ground in one or even a few papers of ordinary length.

The papers presented were divided into five sections:—

Section I Heat Transfer with Change of State.
Section II Heat Transfer between Fluids and Surfaces.
Section III Conduction in Solids and Fluids.
Section IV Radiation, Instrumentation, Measurement Techniques and Analogies.
Section V Special Problems.

The aeronautical engineer will probably find something of value to him in each and all of these sections.

For example, Section I contains papers on Heat Transfer under frosting conditions and on supersaturation in the expansion of steam. Section II contains papers on Heat Transfer in Rarefied Gases and with Section V, covers heat transfer in radiators. This section also includes two papers on the philosophical side of eddy diffusion. In addition to papers obviously indicated by its title, Section III contains several on the unsteady state. Section IV has papers on the cooling of gas turbine blades and the use of interferometric methods to study free convection boundary layer problems. Section V, besides the papers on radiation, has papers on other methods of cooling gas turbine blades and on air condensation in hypersonic wind tunnels.

It is impossible, within the limits of a review, to summarise the contents of this volume, and indeed the method of presentation, by two reporters per section summarising all the papers of that section, makes browsing easy; but anyone connected with aeronautical engineering should at least read the several reports and anyone closely connected with design should study it in detail.—W.F.C.

WEIGHT-STRENGTH ANALYSIS OF AIRCRAFT STRUCTURES. *F. R. Shanley. McGraw Hill, New York 1952. 394 pp. Illustrated. 72s. 6d. net.*

Most of the available literature on structures and strength of materials is based on the *analysis* approach in which a given structure is analysed to determine the stresses resulting from a given system of loads. This book, which is one of a series of publications presenting the results of research undertaken by the Rand Corporation of the U.S.A., represents a distinct contribution to the study of the inverse problem of determining the optimum structure to carry a given system of loads, taking into account any limitations on overall dimensions. Since, in general, comparison of structures and materials on a strength/weight basis may be misleading, particularly in the case of structures which fail by buckling, the book has been written from the point of view of comparison of weight/strength ratio (not necessarily the reciprocal of the strength/weight ratio); this means that consideration is given to predicting the structural weight required to achieve a given strength (or equivalent criterion), not the strength which can be obtained from a given weight.

The book is divided into three parts, and contains, in addition to material forming the subject of Rand reports, reprints of papers which have appeared in the *Journal of the Aeronautical Sciences.*

Part I deals with the principles of structural design for minimum weight. There is no attempt to determine the true optimum structure, taking into account all the factors which may be involved, the treatment being almost entirely from the weight/strength aspect. One chapter in this part, however, is devoted to a discussion of the manner in which stiffness requirements may modify the optimum structure.

In Part II, "Structural Weight Equations," the principles of Part I have been applied to the development of basic equations for the aircraft structure weight. Weight prediction methods in general use are usually semi-empirical in nature, being based partly on statistical analyses of existing aircraft. These methods may be unreliable when applied to types of structure which differ widely from those on which the formulæ and charts are based, and attention has been given, therefore, to the development of weight equations not only for the "conventional" type of structure (*e.g.* skin-stringer-rib construction for wings) but also for types of structure which have not been widely used in the past but which may prove to be more efficient for the very thin wings of new aircraft. The application of the formulæ derived depends ultimately on the determination of some empirical constants and some of the assumptions made could be queried, but the method of approach to the various problems is of considerable interest. A useful chapter is that in which the factors which tend to cause the actual weight to exceed the optimum are analysed and the formulæ are modified to take account of the effects of such items as joints and the use of untapered material.

Part III contains a number of reports which were prepared in the course of investigations of new materials and extreme operating conditions to establish methods by which the effects of temperature and time could be included in structure design and weight calculations. This part, in addition to a discussion of "Stress-strain-time relationships," contains a reprint of Shanley's paper on "Inelastic Column Theory" from the *Journal of the Aeronautical Sciences*, Vol. 13, No. 12, Dec. 1946, together with further chapters on "Creep Buckling."

Apart from its value in bringing together in one volume a large amount of work on structural "design" (as opposed to "analysis"), this book should encourage the further development of the principles of weight/strength analysis and, in particular, the application of the principles of structural design for minimum weight.—R. TATHAM.

PHYSICAL SIMILARITY AND DIMENSIONAL ANALYSIS. *W. J. Duncan. Edward Arnold, London 1953. 156 pp. Diagrams. 30s. net.*

In his preface, the author excuses the appearance of another book on dimensional analysis by its being the first to discuss the subject in its proper content: physical similarity. But he is too modest. As usually presented to the student, dimensional analysis seems mysterious and therefore difficult, so that a book which presents the subject clearly and without mystery is important.

The use of non-dimensional parameters and the methods of dimensional analysis provide such an excellent discipline for the student of physical science, and such a valuable tool for the research worker, that they ought to play a larger part in the curricula of engineering colleges than is usual. Professor Duncan's book, by its lucid exposition, should encourage reform in this, for the student and lecturer could not wish for a better guide. The treatment of dimensional analysis against a background of physical similarity is one factor in creating the lucidity, but also effective are two minor (?) factors: (1) the use of the term "measure formula" of a physical quantity instead of the "dimensions" of that quantity, since the latter term is probably the chief source of mystery to the student; (2) the use of a special symbol ($\triangleq$) instead of the "equals" sign, for the student, rightly, looks askance at such an equation as P (denoting force)$=MLT^{-2}$, and boggles at writing "the dimensions of P are, and so on."

Two chapters are given up to explaining thoroughly and clearly the meaning of "similarity" in physical systems and the conditions which must be satisfied for the existence of similarity between two systems; two chapters also are devoted to the principles of dimensional analysis, its relation to physical similarity, and its applications, with ample warnings of the pitfalls which await the unwary who may attempt to apply the principles to some problem without first sufficiently understanding it. Here, Professor Duncan presses home the fact that, to make the best use of any technique, the user must appreciate its limitations as well as its scope. There is a chapter on the "Pi" theorem, and a wide selection of examples of the application of dimensional analysis to problems in fluid mechanics, thermodynamics, electro-magnetism.

PROCEEDINGS OF THE SOCIETY FOR EXPERIMENTAL STRESS ANALYSIS, Vol. X, No. 1. *Edited by C. V. Maklmann and W. M. Murray. Society for Experimental Stress Analysis. Cambridge, Mass. 1952.*

Although not many of the papers published in this volume can be said to have a direct bearing on aeronautical engineering, this is not to say that they are of no interest to the aeronautical engineer. For there are always valuable lessons to be learnt from experience in other branches of engineering in the application of standard equipment under novel conditions. The ordinary resistance strain gauge, for example, is used here for such diverse purposes as measuring the individual efforts of the members of a racing-eight crew, the stresses and vibrations in the chassis of a motor car at speed, the forces in a bull-dozer in action.

Among the papers of direct aeronautical interest, that by D. A. Drew of Rolls-Royce stands out. This not only describes a routine experimental procedure for measuring vibration stresses in turbines, but also gives a most instructive account of a particular piece of research on the fatigue behaviour of turbine blades. Another good paper describes the technique used at the Naval Research Laboratory, Washington, for determining, from the graphic ground records, the component frequencies and amplitudes of data telemetered from ships, aircraft, rockets and missiles.

One of the trickiest problems in resistance-strain-gauge work is to keep the gauge dry under conditions of dampness or complete immersion. H. O. Meyer of M.I.T. shows, in a letter to the Editor, how he has solved this problem and it is the best solution the reviewer has seen so far.

There are several papers on stress waves set up by impacts. They have a slightly academic flavour, in that the main interest is comparison between theory and experiment, and one wishes that the authors would explain what particular engineering application they have in view.

The problem of "residual stresses," as affecting the fatigue properties of structures, is becoming very important in aeronautics and any data on it from other branches of engineering, such as is given here in a paper on "Residual stresses in oil-field pump rods," is worth studying. There is another paper on the fatigue problem, in which is a projected attempt at either proving or disproving the so-called "cumulative damage rule." The tendency in this country is to discount any such rule and results will therefore be worth watching.

A paper on "A plate analogy as a means of stress analysis" examines a method of deducing the plane stresses in a flat plate from the curvature of the same plate under certain bending forces. It provides a useful warning against the too prevalent error of thinkers that an analogy to any problem is easier to solve than the problem itself.

In other papers are described a "mechanical deflection gauge"; a "strain-cycle gauge and counter"; an "improved photogrid technique"; the "static and creep properties of stress-coat," and the "quenching stresses in a glass sphere."—D. WILLIAMS.

Additions to the Library

American Helicopter Society, Philadelphia Section, and the Institute of the Aeronautical Sciences. SECOND CONVERTIBLE AIRCRAFT CONFERENCE. December 12th 1952.

Brooks, C. E. P. and N. Carruthers. HANDBOOK OF STATISTICAL METHODS IN METEOROLOGY. H.M.S.O. 1953.

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*Reference only.

Reports

AERODYNAMICS

Compressible Flow

The pressure on the surface of a flat elliptic cone set symmetrically in a supersonic stream. D. G. Hurley. A.R.C. Current Paper 109.

The first order solution of the problem of the supersonic flow past a flat elliptic cone set symmetrically to the wind indicates that the pressure over the surface is constant if the body lies within the Mach cone of the apex. This result is incorrect near the leading edges of the cone and an improved solution is derived here by the introduction of line sources near the leading edges. Numerical results are given for three bodies. (1.2.3).

A note on shock tubes. D. W. Holder. A.R.C. Current Paper 110.—(1.2.3).

A method for calculating pressure distributions on circular arc ogives at zero incidence at supersonic speeds, using the Prandtl-Meyer flow relations. H. K. Zienkiewicz. A.R.C. Current Paper 114.

A method is given for a rapid determination of pressure distributions on circular arc ogives at zero incidence at supersonic speeds. The method is based on the characteristics pressure distributions and involves the use of the two-dimensional Prandtl-Meyer flow relations. It gives very good agreement with characteristics results from other sources and with experimental results.—(1.2.3).

Effect of variable viscosity and thermal conductivity on high-speed slip flow between concentric cyclinders. T. C. Lin and R. E. Street. N.A.C.A. Technical Note 2895.

The differential equations of slip-flow, including the Burnett terms, were first solved by Schamberg assuming that the coefficients of viscosity and heat conduction of the gas were constants. The problem is solved herein for variable coefficients of viscosity and thermal conductivity by applying a transformation leading to an iteration method.—(1.2.3 × 1.9).

An application of the method of characteristics to two-dimensional transonic flows with detached shock waves. K. C. Harder and E. B. Klunker. N.A.C.A. Technical Note 2910.

An application of the method of characteristics is presented which affords a means for determining the surface pressures for a class of two-dimensional aerofoils of given nose shape and arbitrary rear part in a sonic or supersonic stream if surface pressure data are given for one member of the class. For engineering purposes, the method of characteristics may be replaced by a simple application of Prandtl-Meyer flow concepts. An explanation of the non-linear force characteristics of two-dimensional aerofoils at transonic speeds is presented on the basis of sensitivity of these flows to changes in geometry and angle of attack.—(1.2.2 × 1.10.1.1).

Control Surfaces

Low speed wind tunnel investigation of tab hinge moment characteristics. W. J. G. Trebble and J. F. Holford. A.R.C. Current Paper 112.

Hinge moments have been been measured on tabs of 4·7 per cent. local chord on a tailplane with 14° trailing edge angle. The range of investigation covered the effects of 32 per cent. nose balance and of the gap between tab and elevator.—(1.3.0).

Effect of horizontal-tail span and vertical location on the aerodynamic characteristics of an unswept tail assembly in sideslip. D. R. Riley. N.A.C.A. Technical Note 2907.

Wind-tunnel results on the effect of horizontal-tail span and vertical location of the horizontal tail relative to the vertical tail on the aerodynamic characteristics of an unswept vertical-tail assembly in sideslip are presented. By applying the well-known discrete-horseshoe-vortex method used for wings to the problem of intersecting surfaces, theoretical span loadings were obtained for each of the configurations tested. Calculated values obtained from the span loadings are compared with experimental results.—(1.3.2).

Fluid Dynamics

The use of influence factors in problems of fluid flow. K. H. V. Britten. R. & M. 2441.

A vigorous mathematical analysis has been applied to some empirical results, obtained by Thom, on the use of the "squares method" in problems of fluid flow. The problem considered is that of determining the incompressible and compressible flow past an arbitrarily shaped body placed in a wind tunnel.—(1.4).

Impingement of cloud droplets on aerodynamic bodies as affected by compressibility of air flow around the body. R. J. Brun, J. S. Serafini and Helen M. Gallagher. N.A.C.A. Technical Note 2903.

The trajectories of water droplets in a compressible-air flow field around a cylinder were computed with a mechanical analog. The results of the calculations at the flight critical Mach number were compared with calculations of trajectories in an incompressible flow field. The results obtained with the cylinder were extended to aerofoils.—(1.4).

Internal Flow

Some curves for use in calculations of the performance of conical centrebody intakes at supersonic speeds and at full mass flow. L. E. Fraenkel. A.R.C. Current Paper 108.

Curves are presented of a number of parameters which frequently occur in calculations of the performance of conical centrebody intakes at supersonic speeds and full mass flow. These parameters follow directly from the theoretical supersonic flow past cones. Semi-cone angles of 15°, 20°, 22·5°, and 30° are considered, and the range of free stream Mach number is approximately 1·3 to 3·0.—(1.5.1).

Study of secondary-flow patterns in an annular cascade of turbine nozzle blades with vortex design. H. E. Rohlik, H. W. Allen and H. Z. Herzig. N.A.C.A. Technical Note 2909.

To increase understanding of the origin of losses in a turbine, the secondary-flow components in the boundary layers and the blade wakes of an annular cascade of turbine nozzle blades (vortex design) were investigated. A detailed study was made of the total-pressure contours and, particularly, of the inner-wall loss cores downstream of the blades. The patterns of secondary flow were determined by use of hydrogen sulfide traces, paint, flow fences, and total-pressure surveys.—(1.5.4).

Loads

Asymmetric tailplane loads due to sideslip. Winfried Braun. A.R.C. Current Paper 119.

A method is derived which estimates the tailplane rolling moment coefficient due to sideslip for use in strength calculations. The investigation covers the contributions to the rolling moment from the end-plate effect at the fin (twin fins are not considered), the dihedral of the tailplane, the effect of the body (which differs on the lee and windward-sides), the effects of sweepback and plan form, and of unsymmetrical lift distribution on the main wing. An allowance is made for the influence of propeller slip-stream, and a tolerance suggested to cover inaccuracies of the method.—(1.6).

A low-speed experimental study of the directional characteristics of a sharp-nosed fuselage through a large angle-of-attack range at zero angle of sideslip. W. Letko. N.A.C.A. Technical Note 2911.

Static yawing moments and some instantaneous yawing moments are presented through a range of angle of attack at zero sideslip angle for a plain fuselage model having a sharp conical nose and for the fuselage with several nose modifications, one of which consisted of a ring located at different stations along the nose. Some circumferential pressure measurements at one station on the body at several angles of attack are also presented.—(1.6).

NOTE:—*The figures in parenthesis at the end of each Summary are for office use only.*

Stability and Control

Measurements of flying qualities of an F-47D-30 airplane to determine longitudinal stability and control and stalling characteristics. C. C. Kraft, Jr., R. F. Goranson and J. P. Reeder. N.A.C.A. Technical Note 2899.

Flight tests were made of the flying qualities of an F-47D-30 aeroplane to determine the longitudinal stability and control and stalling characteristics.—(1.8.2).

Matrix methods for determining the longitudinal-stability derivatives of an airplane from transient flight data. J. J. Donegan. N.A.C.A. Technical Note 2902.

Three methods are presented for calculating the longitudinal stability derivatives from transient flight data. Several examples using flight data are given to illustrate the method. The results indicate the scatter which is typical of this type of analysis.—(1.8.2).

Wings and Aerofoils

A note on the estimation of some low speed characteristics of delta wings. R. G. Rose. Cranfield Report 68.

The results of the Weissinger swept lifting line theory have been compared with other methods and experimental results. On the basis of this comparison empirical corrections to the Weissinger theory results have been suggested in some cases. Charts have been prepared which enable an estimate to be made of the lift curve slope at zero lift, the location of the aerodynamic centre, and the rolling and yawing characteristics at low incidence. The estimation of $C_{L\max}$ and $\alpha_{C_{L\max}}$ are also briefly considered.—(1.10.1.2).

Charts of the wave drag of wings at zero lift. T. Lawrence. A.R.C. Current Paper 116.

Theoretical calculations of the wave drag at supersonic speeds of non-lifting wings of double wedge and biconvex section are reviewed, and the best method of presenting the results considered. Using this method, a representative selection of the available numerical evaluations of the theory are presented. These should be of value for wing drag estimation purposes.—(1.10.1.2).

*The generalization of Prandtl's equation for yawed and swept wings. A. I. Van de Vooren. N.L.L. Report F.*121.

By neglecting in the formulæ for the downwash in lifting surface theory all terms which are inversely proportional to the second or higher powers of the aspect ratio, simplified formulæ are obtained yielding the Prandtl equation in the case of straight, unyawed wings. For yawed and swept wings the generalised Prandtl equation shows that the finite span effects consist of a modification of the profile characteristics (induced camber) and of the reduction of the geometric angle of incidence to an effective value.—(1.10.1.2).

*Examples of drag reduction for rectangular wings. K. Walker, Jr. Douglas Report SM-*14446.

Graham's method for reducing the drag of fixed plan form wings is applied to rectangular wings. The drag due to lift is reduced by adjusting the twist and camber of the mean surface while preserving constant total lift. The thickness drag is reduced by adjusting the thickness distribution while maintaining constant total volume or total frontal area or the distribution of thickness along the mid-chord line. Non-viscous linearised supersonic wing theory is employed.—(1.10.1.2).

*Examples of drag reduction for delta wings. B. Beane. Douglas Report SM-*14447.

E. W. Graham's method for reducing the drag of fixed plan form wings is applied to delta wings. The drag due to lift is reduced by adjusting the twist and camber of the mean surface while preserving constant total lift. The thickness drag is reduced by adjusting the thickness distribution while maintaining constant total volume or total frontal area. Non-viscous linearised supersonic wing theory is employed.—(1.10.1.2).

Theoretical calculation of the pressure distribution, span loading, and rolling moment due to sideslip at supersonic speeds for thin sweptback tapered wings with supersonic trailing edges and wing tips parallel to the axis of wing symmetry. K. Margolis, W. L. Sherman and Margery E. Hannah. N.A.C.A. Technical Note 2898.

On the basis of linearised supersonic-flow theory, equations for the pressure distribution have been derived for thin, swept-back, tapered wings sideslipping at a constant angle of attack. The analysis is applicable to plan forms for which the wing tips are parallel to the axis of wing symmetry and at supersonic speeds for which the wing trailing edge is supersonic. The plan form with both leading edges subsonic has been analysed in detail. Equations for the span loading, rolling moment, and the corresponding stability derivative $C_{l\beta}$ have been obtained. Illustrative span loadings and variations of the derivative $C_{l\beta}$ with Mach number are presented for a number of wings.—(1.10.1.2).

The calculation of pressure on slender airplanes in subsonic and supersonic flow. M. A. Heaslet and H. Lomax. N.A.C.A. Technical Note 2900.

Under the assumption that a wing, body, or wing-body combination is slender or flying at near sonic velocity, expressions are given which permit the calculation of pressure in the immediate vicinity of the configuration. A discussion is also given of couplings, between lifting and thickness effects, that necessarily arise as a result of the quadratic dependence of pressure on the induced velocity components.—(1.10.1.2 × 1.4).

AEROELASTICITY

Higher harmonics of flapping on the helicopter rotor. W. Stewart. A.R.C. Current Paper 121.

The amplitudes of the flapping harmonics up to the sixth harmonic have been calculated for a range of blade pitch and blade inertia number for tip speed ratios up to 0·6. The calculations are for a straight (infinitely rigid) blade and blade stalling is not taken into account. The results are given in the form of generalised curves.—(2).

*Parameters for use in buffeting flight tests. H. W. Liepmann. Douglas Report SM-*14631.

Buffeting is considered as the response of an elastic aeroplane structure to random forces. Using dimensional analysis and similarity considerations, the velocity and altitude dependency of the increased stress at a point of a given aeroplane is investigated.—(2).

Evaluation of gust response characteristics of some existing aircraft with wing bending flexibility included. E. E. Kordes and J. C. Houbolt. N.A.C.A. Technical Note 2897.

Calculation studies made by means of the analysis presented in N.A.C.A. TN 2763 to evaluate the influence that wing bending flexibility has on the structural response due to gust are reported for three twin-engine transports and one four-engine bomber. The manner in which dynamic response factors for acceleration and bending moment vary with various assumed operational factors is shown. Factors investigated include gust-gradient distance, gust shape, spanwise mass distribution, forward velocity, altitude, and compressibility and aspect-ratio corrections. A limited correlation of some of the calculated results with flight data is also presented.—(2 × 33.1.2).

An analysis of the factors affecting the loss in lift and shift in aerodynamic center produced by the distortion of a swept wing under aerodynamic load. C. W. Mathews and M. C. Kurbjun. N.A.C.A. Technical Note 2901.

Results of a simplified analysis of the factors affecting the loss in lift and shift in aerodynamic centre of a swept wing due to its bending under aerodynamic load are presented as charts which relate the stress and aeroelastic effects considered to the wing structural weight, external geometry, material, and flight condition. Illustrative examples of the magnitudes of the aeroelastic effects to be expected are presented for typical swept wings. The manner in which these aeroelastic effects influence the longitudinal stability of an aeroplane is also considered.—(2 × 1.8.2).

AIRCRAFT OPERATION

A method for rapid determination of the icing limit of a body in terms of the stream conditions. E. E. Callaghan and J. S. Serafini. N.A.C.A. Technical Note 2914.

The effects of existing frictional heating were analysed to determine the conditions under which ice formations on

aircraft surfaces can be prevented. A method is presented for determining rapidly by means of charts the combination of Mach number, altitude, and stream temperature which will maintain an ice-free surface in an icing cloud. The method can be applied to both subsonic and supersonic flow. The charts presented are for Mach numbers up to 1·8 and pressure altitudes from sea level to 45,000 ft.—(5.4).

FLIGHT TESTING

Some basic concepts for analyzing dynamic flight test data. H. Klein and R. Sedney. Douglas Report SM-14511.

The problem considered here is that of finding through the use of observed data the coefficients of the differential equations that describe a dynamic system. This problem occurs in the determination of the aerodynamic stability derivatives of an aeroplane or missile from flight test data. There is a maximum number of coefficients which may be determined. A method is given for finding this number and conditions are given under which the maximum number is obtained. These results are summarised in a working rule and applied to two examples. It is shown that the free oscillation type of flight testing can never yield all the coefficients. Suitable forcing functions are described which do permit all coefficients to be evaluated.—(13.2).

MATERIALS

The fatigue of duralumin with reference to its application for connecting rods. F. G. Lewis. A.R.L. Australia. Structures and Materials Note 202.

A survey of the literature shows that the fatigue properties of duralumin under reversed bending and direct stress have been widely studied. Limited investigation has been made on the fatigue properties of duralumin connecting rods under simulated service conditions and they have proved satisfactory. The notch sensitivity of duralumin is discussed and it is shown that the alloy is relatively insensitive to notches. Shot peening as a means of improving fatigue life is also considered but there is relatively little data available for duralumin.—(21.2.2).

Effect of processing variables on the transition temperature, strength, and ductility of high-purity, sintered, wrought molybdenum metal. K. C. Dike and R. A. Long. N.A.C.A. Technical Note 2915.

An investigation was made of the effect of processing variables on the properties of sintered, wrought molybdenum. The amount of swaging, recrystallisation, and stress-relieving were considered. All the material evaluated in tension, irrespective of the amount of swaging, whether in the as-swaged, stress-relieved, or recrystallised state showed a transgranular fracture at all temperatures.—(21.1 × 21.2.2).

MATHEMATICS

An approximate method of deriving the transient response of a linear system from the frequency response. C. A. A. Wass and E. G. Hayman. A.R.C. Current Paper 113.

There are several published methods of deriving the transient response of a linear system from the known frequency response, but these are more rapid, although less accurate. It is based on the calculation of the response of the system to a square wave as expressed by a Fourier Series. For any system there is an optimum square wave frequency, and the process of selection of this fundamental frequency is described. It is shown that consideration of responses up to the eleventh harmonic only can give transient response curves which are in error by less than 2 per cent. A description is given of a circular computor which speeds the calculations, and two tables of values are included for use with the computor.—(22.2).

POWER PLANTS

A method of estimating optimum turbine operating conditions for a range of nozzle and blade angles. E. Duncombe. N.A.E. Canada. Report 17.

A study of previous turbine cascade results enables a summarised chart of optimum performance, which can be expected from nozzles and blades to give prescribed gas angles, to be developed. A stage-by-stage method of calculating turbine characteristics for compressible flow is then introduced, which is flexible enough to cater for off-design-point nozzle and blade efficiencies and enables a study to be made of the effects of nozzle and blade choking conditions.—(27.1 × 1.5.3).

Le statoréacteur supersonique aux nombres de Mach moderès. M. Salmon. Publications Scientifiques et Techniques du Ministère de L'Air. No. 274.—(27.4).

Theoretical and measured attenuation of mufflers at room temperature without flow, with comments on engine-exhaust muffler design. D. D. Davis, Jr. et al. N.A.C.A. Technical Note 2893.

Equations are presented for the attenuation characteristics of several types of mufflers. Experimental curves of attenuation plotted against frequency are presented for 77 different mufflers and the results are compared with theory. The experiments were made at room temperature without flow and the sound source was a loud-speaker. A method is given for including the tail pipe in the calculations. The application of the theory to the design of engine-exhaust mufflers is discussed, and charts have been included for the assistance of the designer.—(27.2.1).

RESEARCH

Some tests of a refrigerated rotating cylinder for measuring ice accretion. B. Quan and H. G. Wenham. N.A.E. Canada. Laboratory Report LR-45.

Under certain icing conditions, a large proportion of the water impinging on an uncooled rotating cylinder or on a cylindrical ice detector head blows off before it can freeze. Some comparative measurements of liquid water content were made during the winter of 1951-52 using rotating cylinders uncooled and cooled by expanding carbon dioxide through the hollow centre.—(31.1 × 24).

An airborne indicator for measuring vertical velocity of airplanes at wheel contact. R. C. Dreher. N.A.C.A. Technical Note 2906.

An investigation has been made with an airborne vertical-velocity indicator in order to determine the accuracy and practicability of such an indicator. A prototype installation was tested under controlled conditions in the Langley impact basin and by means of flight tests with a small trainer-type aeroplane. A second more compact installation which is retractable was developed for use on a high-speed jet bomber. A description of the operation of the indicator is given.—(31.1 × 33.1.2).

STRUCTURES

LOADS—*see also* THEORY AND ANALYSIS

Tailplane loads and normal accelerations after an automatic control failure. J. L. Reddaway. A.R.C. Current Paper 111.

A method is given for the calculation of aircraft behaviour when failure of the autopilot produces sudden elevator movements. Expressions for the changes in aircraft normal acceleration, tail unit accelerations and aerodynamic tail loads are derived. These expressions together with their maxima and the times taken to reach these maxima are tabulated. A calculation on a specific aircraft shows the use of the table.—(33.1.2).

V-g records from "Mustang" aircraft in training. Queenie Ferstat. A.R.L. Australia. Structures and Materials Note 192.

In order to obtain data on the occurrence of high loads on aircraft used during training in the Royal Australian Air Force, *V-g* recorders were fitted to several Mustang aircraft at a Training School in Victoria. The recording period covered 102·5 flying hours. The unfactored design flight envelope was not exceeded during this period, the highest load factor of $n=7·3$ occurring during general flying (duty unspecified). The highest speed was well below the maximum permissible.—(33.1.1 × 33.1.2).

On travelling waves in beams. R. W. Leonard and B. Budiansky. N.A.C.A. Technical Note 2874.

The basic equations of Timoshenko for the motion of vibrating non-uniform beams, which allow for effects of transverse shear deformation and rotary inertia, are presented in several forms; the propagation of sharp disturbances is

discussed. Numerical travelling-wave solutions are obtained for some elementary problems of finite uniform beams for which the propagation velocities of shear and bending discontinuities are equal. Comparisons are made with modal solutions and, in some cases, with exact closed solutions.—(33.1.2).

On the use of a damped sine-wave elevator motion for computing the design maneuvering horizontal-tail load. M. Sadoff. N.A.C.A. Technical Note 2877.

An analysis was made to evaluate the assumption of a damped sine-wave elevator motion for computing the design manœuvring load on the horizontal tail. Also investigated was the effect of control frequency on the tail load. The results indicated that the tail loads computed by the method of the present report agreed closely with the loads computed by a method currently specified for use in the U.S. Air Force structural loading departments. For a given design normal acceleration factor, it was found that an increase in control frequency resulted in a marked increase in both the negative and positive peak tail loads attained during the assumed manœuvres.—(33.1.2).

THEORY AND ANALYSIS

The effect of spanwise rib-boom stiffness on the stress distribution near a wing cut-out. E. H. Mansfield. R. & M. 2663.

A theoretical investigation is made into the effect of spanwise rib-boom stiffness on the stress distribution at a cut-out in the inter-spar skin of a stressed skin wing in bending. Both shear and bending stiffness of the rib-boom are taken into account, and attention is concentrated on the case in which the rib-boom is built-in to the spar flanges. Curves are included which determine, for any particular case, the magnitude of the peak shear stress adjacent to the flange, the approximate spanwise variation of this shear stress, the proportion of load transferred by the rib-boom to the skin and stringers, and the bending moment in the rib-boom at its points of attachment to the spar flanges.—(33.2.3).

Analysis of two-cell swept box with ribs parallel to the line of flight under loading by constant couples. D. Howe. Cranfield. Report 64.

The method of oblique co-ordinates is used to analyse the problem associated with the strength and deformation of a uniform, rectangular, two-cell swept box beam having ribs parallel to the line of flight. The case of loading by constant couples is considered, but no account of root effects is taken. The ribs are assumed to be continuously distributed, the rib boom area, together with the stringer area, being distributed over the skins. A degree of flexibility is allowed to the rib webs.—(33.2.3).

*Torsion and bending of swept and tapered wings with rigid chordwise ribs. W. H. Wittrick. Department of Supply, Australia. Report ACA-*51.

The problem considered is that of a swept wing, either conical or cylindrical, of arbitrary section, under any system of bending and torsion loads. The wing is assumed to consist of a non-buckling outer skin, a series of booms and stringers located along generators of the tube, and a series of closely spaced ribs all parallel to the root section. The ribs are assumed to be completely rigid in their own planes but to offer no resistance to warping out of their planes. For simplicity only single-cell tubes are considered. The theory is developed in general terms (Part I) for arbitrary section, arbitrary variation of stress bearing area over the tube, and arbitrary applied loads. No restriction is placed on either the taper or the sweep of the tube. The computation can all be done in tabular form and is illustrated numerically in Part III. As yet no method convenient for dealing with the restricted regions has been found. With a highly tapered wing it is shown (Part II) that the root effect is of prime importance, since the stresses arising from the warping constraint at the root decay very slowly along the length of the tube. This fact considerably complicates the analysis of such wings.—(33.2.3).

*The deformation analysis of tapered swept wings. A. H. Hall. N.A.E. Canada. Laboratory Report LR-*44.

A method is outlined for applying the deformation relations derived in N.A.E. Laboratory Report LR-28 for wings without taper, to the analysis of wings with a moderate degree of taper. By way of illustration, the experimental results for wing models of cellulose acetate yawed at 0 degrees, 30°, 45° and 60° were used. The unswept plan form of these models provided, approximately, $A.R. = 3{\cdot}5$ and taper ratio $c_T/c_R = 0{\cdot}5$.—(33.2.3).

The effect of longitudinal stiffeners located on one side of a plate on the compressive buckling stress of the plate-stiffener combination. P. Seide. N.A.C.A. Technical Note 2873.

The problem of buckling under uniform compression of flat, simply supported, rectangular plates with equally spaced longitudinal stiffeners on one side of the plate is investigated. For the case of a plate with one, two, or infinitely many stiffeners, the analysis yields expressions for the effective moment of inertia of the stiffeners that can be used in conjunction with the buckling charts previously presented in N.A.C.A. T.N.1825.—(33.2.4).

The effect of initial curvature on the strength of an inelastic column. T. W. Wilder, III, et al. N.A.C.A. Technical Note 2872.

The reduction in column strength due to initial curvature is determined theoretically for a pin-ended idealised inelastic H-section column. Equations relating load and lateral deflection are obtained which permit a systematic variation in the parameters representing the stress-strain properties, column proportions, and initial curvature of the column. The results, presented graphically, show the effect on column strength for various combinations of these parameters.—(33.2.2 × 33.2.4).

Behavior in pure bending of a long monocoque beam of circular-arc cross section. R. W. Fralich, J. Mayers and E. Reissner. N.A.C.A. Technical Note 2875.

An analysis is made of the behaviour under a loading of pure bending moment of a thin, infinitely long, pure-monocoque beam having a constant, doubly symmetric, circular-arc cross section. Bending moments, deflections, and stresses are obtained. The analysis shows a non-linear behaviour in bending which leads ultimately to a maximum moment and instability.—(33.2.4).

Calculation and measurement of normal modes of vibration of an aluminium-alloy box beam with and without large discontinuities. F. C. Smith and D. M. Howard. N.A.C.A. Technical Note 2884.

The lowest normal modes of vibration of three aluminium alloy box beams were calculated using a matrix iteration method. For the calculations the actual structures were idealised to a system of mass points interconnected by massless springs. The lowest normal modes of these beams were measured experimentally and compared with those calculated. This comparison indicates that the mode shapes and natural frequencies for structures of this type may be adequately calculated using this method. The experimental measurements were limited at the higher frequencies by local vibrations of small elements of the beams.—(33.2.3 × 31.1.2).

An analysis of statically indeterminate trusses having members stressed beyond the proportional limit. T. W. Wilder, III. N.A.C.A. Technical Note 2886.

A procedure for analysing statically indeterminate trusses in the plastic stress range is presented which is applicable to trusses having any number of redundant members. By using the Ramberg-Osgood analytical representation of the stress-strain curve, the analysis of the truss is reduced to the solution of a set of simultaneous equations. A numerical example is given to illustrate the procedure.—(33.2.2 × 33.2.3).

THERMODYNAMICS

Carbon formation in flames of aromatic hydrocarbons. W. Sacks and M. T. I. Ziebell. N.A.E. Canada. Report 18.

A new type of burner was employed to investigate the effect of aromatic structure on carbon formation. The liquid hydrocarbons were burned in a cone with a constant air supply. The resulting diffusion flame was very stable and the carbon stream from the flame was impinged on platinum gauze collectors.—(34.1.1).

Temperature et equilibre termique dans une flamme de diffusion. Publications Scientifiques et Techniques du Ministère de L'Air, No. 273.—(34.1.1).